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Thijssen, Gerardus Johannes

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OF DUTCH DAIRY FARMS

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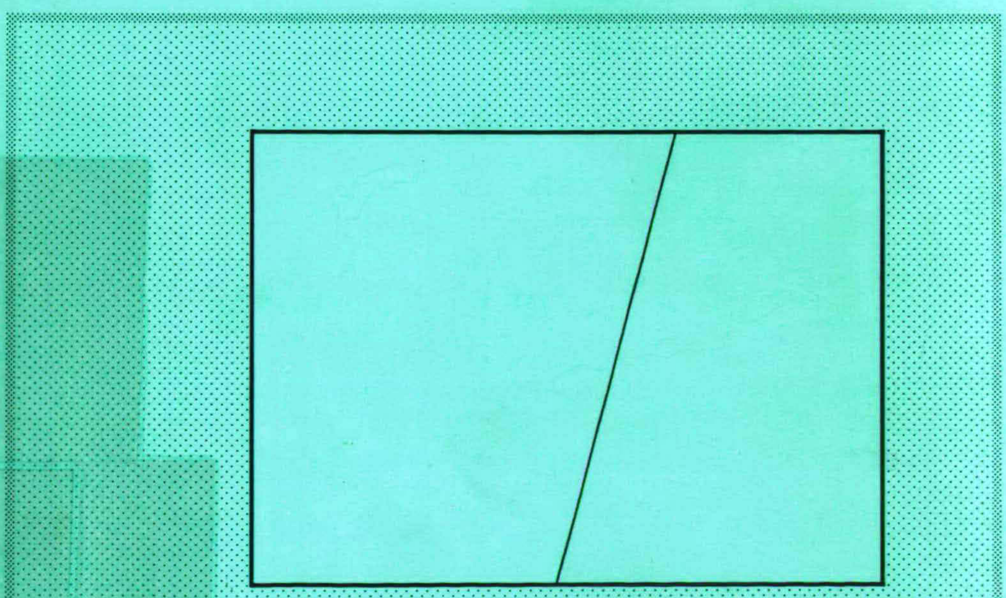

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MICRO-ECONOMIC MODELS OF DUTCH DAIRY FARMS

Proefschrift ter verkrijging van de graad van doctor
aan de Katholieke Universiteit Brabant,
op gezag van de rector magnificus, prof.dr. L.F.W. de Klerk,
in het openbaar te verdedigen ten overstaan van
een door het college van dekanen aangewezen commissie
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door

Gerardus Johannes Thijssen,

geboren te Haelen (Limburg)

Promotor: prof.dr.ir. A. Kapteyn

Assistent-promotor: dr.ir. A.J. Oskam

PREFACE

The research presented in this thesis was carried out at the Department of Agricultural Economics and Policy of Wageningen Agricultural University. Large parts of this study have already been published as working papers or journal articles.

Chapter 2 is identical to Thijssen (1992a), which appeared in the *European Review of Agricultural Economics.*

Chapter 3 is identical to Thijssen (1992b), which appeared in the *European Review of Agricultural Economics.*

Chapter 4 is a revised version of Thijssen (1988), which appeared in the *European Review of Agricultural Economics.*

Chapter 5 is a revised version of Thijssen (1989).

Chapter 6 is a paper presented at the XXI International Conference of Agricultural Economists, Tokyo, Japan (Thijssen, 1991).

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I am much indebted to Arie Kapteyn and Arie Oskam for their support, constructive criticism and valuable suggestions. Arie Kapteyn increased my knowledge about econometrics and stimulated me in developing a professional attitude. Arie Oskam proposed some of the topics to me, increased my knowledge about agricultural economics and created a stimulating research environment.

I am grateful to a number of colleagues who made helpful comments on papers underlying this thesis. In particular I would like to mention Rob Alessie, Kees Burger, Paul Elhorst, Douwe Kingma, Erno Kuiper, Frans Palm, Uptal Vasavada, Marno Verbeek, Dominique Vermersch, Tom Wansbeek, and the colleagues of the Department of Agricultural Economics and Policy. Louis Slangen contributed to my agricultural knowledge and Wilbert Houweling assisted me in the computational work. Further I wish to mention that the interuniversity Network for Quantitative Economics courses given by Tom Wansbeek and Geert Ridder on panel data and the course given by Frans Palm on dynamic econometric modelling were very stimulating. Special thanks go to Jan Magnus, Piet van den Noort, Arthur van Soest and Uptal Vasavada for their willingness to participate in the Ph.D. committee.

The willingness of the Agricultural Economics Research Institute in The Hague to make the data available for this study is gratefully acknowledged. M. Arellano and S. Bond kindly provided their computer program for dynamic panel data estimation. I also want to thank the 'LEB fonds' Foundation for its financial support for the publication of this thesis.

I wish to thank Joy Burrough for correcting and editing my English. Olga Hitters performed an excellent job in typing the formulas, the tables and parts of the book, and preparing the final lay-out. Els Puyk designed the cover.

Last, but not least, I would like to thank Rinie, who has sustained me with her love and understanding during the trials and tribulations encountered in writing this book.

Geert Thijssen
Wageningen, March 1992

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Scope

In agricultural economics the determinants of agricultural production are of central concern. Much attention is paid to (i) the factors influencing the supply of agricultural products, (ii) the factors governing the usage of inputs, and (iii) the impact of technical change. Many of the studies undertaken have two characteristics in common: the models are usually rather loosely based on production theory, and aggregate time series data have been used for estimation.

The past decades have witnessed four important developments in the study of applied production economics:

- the widespread adoption of duality theory: the use of the profit and cost function approach now dominates applied production economics (e.g. Lau, 1978; Chambers, 1988);
- models of agricultural households: the production and labour decisions of a farm household have been integrated into a unified theoretical framework (e.g. Lopez, 1984b; Singh et al., 1986a);
- a consistent dynamic equation system of factor demand has been developed, based on the adjustment cost hypothesis (e.g. Lucas, 1967; Denny, Fuss and Waverman, 1981);
- the rational expectations hypothesis has been an important development in the study of the expectations formation process (e.g. Sargent, 1978; Pfann, 1989).

In addition, empirical research in economics has been enriched by the availability of a wealth of new sources of data: cross sections of individuals observed over time. These allow us to construct and test more realistic behavioural models that could not be identified using only a cross section or a single time-series data. New econometric methods have been introduced to analyse these panel data (Hsiao, 1986).

The prime objective of the study described here was to develop micro-economic models for analysing the determinants of agricultural production. New developments in production economics and estimating techniques for panel data were used. A distinctive feature of an empirical micro-economic model is the close connection between economic theory and empirical implementation. The economic theory used is formulated in terms of individual decision-making units. Having data on the individual units makes it possible to use the theory fruitfully. However, many assumptions have to be made when building a micro-economic model. Some of them are discussed in Section 1.2.

The second objective of this study was to clarify the influence of prices of outputs and inputs, technical change, and the amount of farm land on the supply of the output, the demand for the variable inputs, the supply of labour, and the demand for capital goods of Dutch dairy farms. Dairy farming sector is a very important sector of Dutch agriculture. The farms are similar, which is important for the empirical analysis. The 1970-1982 period was chosen for study because many interesting developments occurred then, see Section 1.3. In 1984 the superlevy system was introduced in the EC, and hence also in the Netherlands. Therefore, a different model has to be used to analyse the period after 1984 (Elhorst, 1990; Helming et al., 1992). The elasticity estimates give measures for the influence of policies at the farm level. Levies and subsidies on prices of inputs and outputs are important instruments in agricultural policy and in environmental policy relating to agriculture.

1.2 The models

In this study, empirical micro-economic models of the production behaviour of farm households were developed from neoclassical theory. The basic assumptions about the farm family are: it optimizes, it is confronted by technical constraints, and it is a price-taker in the output and inputs markets. Further assumptions are necessary if a quantitative model is to be built. In this thesis various assumptions will be analysed:

- should you start from a primal or a dual approach? (Chapter 2)
- are the intercepts treated as fixed or random effects? (Chapter 3)
- is utility or profit maximized by the farm family? (Chapter 4)
- does the farm family maximize short-run profit or does it maximize the present value of income over an infinite horizon? (Chapter 5)
- does the farm family has static or rational expectations about the future path of prices? (Chapter 6).

Other authors have suggested answers to these questions. Table 1.1 indicates those that are referred to throughout the thesis.

Table 1.1 Overview of applied studies in agricultural economics drawn on for this study

First author	Period & country	Data	Approach	Objective	Term	Expectations
Ball (1988)	1948-1979 US	time-series	dual	profit max.	full-static	static
Binswanger (1974)	'49,'54 '59,'64 US	panel state	dual	cost min.	full-static	static
Burrell (1989)	1960-1985 UK	time-series	dual/ ad hoc	profit max.	short run	static
Elhorst (1986)	1975-1982 Netherlands	panel farm	primal & dual	profit max.	short run	static
Elhorst (1990)	1980-1986 Netherlands	panel farm	dual	utility max.	short run	static
Higgens (1986)	1982 Ireland	cross-section	dual	profit max.	short run	static
Jacoby (1990)	1985 Peru	cross-section	ad hoc	utility max.	short run	static
Lopez (1984b)	1970 Canada	cross-section	dual	utility max.	full-static	static
Lopez (1985)	1961-1979 Canada	time-series	dual	profit max.	dynamic	static
McKay (1982)	1952-1976 Australia	time-series	dual	profit max.	short run	static
Oskam (1982)	1959-1979 Netherlands	time-series	ad hoc	profit max.	dynamic	non-static
Stefanou (1992)	1982-1985 Germany	panel farm	dual	cost min.	dynamic	static
Vasavada (1986)	1947-1979 US	time-series	dual	profit max.	dynamic	static

Primal or dual approach?

The basic neoclassical assumption in this study is optimizing behaviour by the farm family, subject to a certain production technology. The production function framework has often been used to describe the production technology in applications of neoclassical theory. During the 1970s and 1980s the profit function approach gained popularity as a tool for estimating elasticities of prices, see Table 1.1. Given a well behaved profit function, duality theory ensures that there is a well behaved technology corresponding to the profit function. From the standpoint of theory it is a matter of indifference as to which approach is used to measure the properties of technology. But deciding whether to focus on the primal problem and specify a production function, or to focus on the dual problem and specify a profit function involves choosing between two different representations of the technology if the functional forms used are flexible and not self-dual.

In Chapter 2 the production technology was described by a primal model and a dual model. The primal model consists of a translog production function and the related share function for the variable input; the dual model consists of a translog profit function and the related share function for the variable input. The production technology is described by production elasticities, substitution possibilities, returns to scale and bias in technology. To compare the results obtained from the primal system with those obtained from the dual system, variances of the elasticities were calculated in an appropriate way. The equations were estimated using the fixed effects estimator, and instrumental variables whenever needed.

The differences between production and substitution elasticities calculated by both models are not significant. Therefore, the primal and dual approaches are not significantly different. The dual approach is used throughout the thesis, because it simplifies and clarifies derivations and results that are otherwise quite difficult.

Fixed or random effects?

A short-run model based on duality theory was developed and estimated in Chapter 3. The short-run profit function is assumed to be quadratic just as in the remaining part of the study. This functional form is also flexible, but in contrast to the translog form it is self-dual. Advantages of the quadratic functional form are that explicit forms of demand and supply equations can be obtained, and that theoretical restrictions can be tested globally. According to Hotelling's Lemma, differentiation of the profit function to the price yields a linear demand function for the variable input and a linear supply function of the output.

The availability of panel data was explicitly taken into account, in the sense that the intercepts of the different equations vary over the farms. In the literature, only aggregate data over a time period are usually available, see Table 1.1. Higgens, Jacoby and Lopez used a cross-section of farms. Only Binswanger, Elhorst and Stefanou had panel data. Binswanger had data from 39 states over four years and Stefanou had averages of 33 farms over four years. Elhorst had the same set of data as used in this thesis, but only took account of the panel structure of the data in the profit function of his 1990 study.

The intercept in the demand function for the variable input and the intercept in the output supply function vary among the dairy farms studied. It turns out that these intercepts are not the same for all farms. The farm intercept reflects differences in the quality of inputs across farms and consists mainly of differences in management and in the quality of land. In the fixed effects model the intercepts are treated as fixed parameters, whereas in the random effects model the intercepts are treated as a sample of random drawings from a population, and they become part of the model's disturbance term. The random effects estimator is generally more efficient than the fixed effects estimator. However, if the random effects estimator is to be consistent it must be assumed that the individual effects and the regressors are independent. A Hausman test rejects this assumption. Therefore, throughout the study fixed effects are assumed.

Utility or profit maximization?

In Chapters 2 and 3 it is assumed, as in many other studies (see Table 1.1), that the farm family's objective is to maximize short-run profit. The focus is on the output supply and the demand for the variable input. Labour is assumed to be fixed. In Chapter 4 labour was introduced as a variable input in the model. The micro-economic model accounts for the interdependence of the farm production unit and the farm household as a unit consuming goods and leisure. The theory starts from a utility function, with consumption goods and leisure as arguments. These two variables are linked through the definition of income and a profit function. The derived budget constraint is non-linear. It was linearized, using a local linear approximation, because otherwise the body of established theoretical results of traditional demand theory cannot be exploited. Using duality theory a labour supply function was derived from the cost function underlying the Almost Ideal Demand System. The supply of labour is a function of the marginal wage rate of labour on the farm. The marginal wage rate was calculated using the profit function. The model consists of the profit function and the related demand function for the variable input, and the supply function of labour. The equations were estimated using the fixed effects estimator and instrumental variables, whenever needed.

Endogenising labour in a model of the farm family have little influence on how farmers reacted to changed prices. Therefore, in the remaining part of this study profit-maximizing behaviour is assumed.

A dynamic model?

Models of output supply and input demand can be grouped into three categories. The first, and most popular (see Table 1.1), starts from the assumption that the firm's objective is to maximize short-run profits. The firm is in static equilibrium with respect to outputs and a subset of inputs (the variable inputs) that is conditional on the level of the remaining inputs (fixed inputs). The second category of model relies on the assumption that there are no fixed inputs: the firm is in (full) static equilibrium with respect to outputs and all the inputs. The third category of model is a dynamic model. It is assumed that some of the inputs on the firm are quasi-fixed; these are inputs which can adjust only at some cost.

A model of dynamic factor demand was developed in Chapter 5 by considering a farm family which maximizes the present value of income over an infinite horizon with respect to two inputs. The two inputs are a variable input and a quasi-fixed input (capital). The farm's objective can be viewed as first having to maximize short-run profits with respect to the variable input and then to maximize the present value of its long-run profits. Therefore, the short-run profit is conditional upon a fixed level of the capital stock, as in Chapters 2, 3 and 4. The farm partly adjusts the capital stock towards the optimal stock at an adjustment rate directly related to the difference between the optimal stock and the actual stock. The optimal capital stock is given by the condition that the marginal return to capital is equal to the user cost of capital. The adjustment rate depends on the discount rate, on the parameters and variables determining the short-run profit function and the adjustment costs. The dynamic model consists of the demand function for capital, the short-run profit function and the related short-run variable input demand function. In dynamic models the fixed effects estimator is not consistent. Therefore, an instrumental variable estimator was used, based on first differences of the variables. From this model the expression for short-, intermediate- and long-run own-price, cross-price and fixed inputs elasticities were derived that completely summarize the dynamic time paths of output supply and input demands.

The hypothesis of instantaneous capital adjustment to changing prices is statistically rejected. Capital adjustment costs play a substantial role in determining short-run and intermediate-run behavioural responses. Therefore, throughout the study the assumption of full static equilibrium has not been used.

Static or rational expectations?
An important assumption in the Chapters 2, 3, 4 and 5, and in the literature (see Table 1.1), is that the farm family has static expectations regarding the evolution of the prices and the fixed inputs: expectations of the price variables and the fixed inputs are fixed at the current level for all future periods.

In Chapter 6, the central aim is to model the farmers' formation of expectations about the future path of variables, using an intertemporal profit-maximizing model and adjustment costs. Two alternative forms were proposed and developed for purposes of comparison: static expectations and rational expectations. In the model based on rational expectations the farm family uses all relevant and available information, including the prices of inputs and output and the levels of the fixed inputs, to choose contingency plans for the variable input and the quasi-fixed input. In order to estimate the parameters of the first order conditions the generalized method of moments (GMM) was applied. The expectation of the quasi-fixed input (the same holds for prices) is equal to the real level of the quasi-fixed input plus a forecast error. This forecast error does not correlate with lagged variables, as it is orthogonal to the available information set.

Both models were estimated using a special program for dynamic panel data which makes it possible to take into consideration a special set of instruments, to take account of the specific structure of the error terms, and to do several tests.

1.3 Data

The data used are from a sample of Dutch farms that kept accounts of their farming for the Agricultural Economics Research Institute. Annual data from dairy farms over the period 1970-1982 were used for estimating the model. The farms usually remain in the panel for about five years. The data set forms an incomplete panel. In total there are 2348 observations and 720 different farms in the sample. For an overview of the number of records on each farm, see Appendix A. Only privately owned farms are considered. No information about the capital volume of the buildings of the tenant farmers is available. Dairy farms are defined as farms where the value of milk and beef production is more than 80% of total production value.

The models include four inputs: variable input, labour, capital, and land. Variable input consists of concentrated feed (0.53), fertilizer (0.13), purchased roughage (0.12), contract work (0.07), feed for pigs (0.06), feed for calves (0.04), fuel (0.03), pesticides (0.01), seed (0.01) (in parentheses the proportions from the average farm of 1980). Labour is family labour and hired labour, measured in hours. The amount of hired labour in the sample is very small, 5% of total labour volume. The amount of family labour is the calculated remuneration of family labour divided by the hourly wage of a farm worker. The hours worked by children are calculated by a smaller remuneration than the hours worked by the farmer, therefore the total hours worked by the farm family is to some degree corrected for differences in quality of family labour. Capital has the following components: livestock (0.36), buildings (0.41) and machinery (0.23) (in parentheses the proportions from the average farm of 1980). The amount of land is total land farmed in hectares. One output is included in the models. The output has the components milk (0.76), meat (0.16), and other outputs (0.08) (in parentheses the proportions of the average farm of 1980).

Profit is defined as the value of output minus the value of variable input. Technical change is, as usual, captured in a trend term.

Table 1.2 Brief description of the 1970-1982 data used in the study

	Mean	Standard deviation	Minimum value	Maximum value
Output (1000 guilders)*	203.5	128.7	13.8	1083.1
Variable input (1000 guilders)*	87.5	62.4	3.8	481.3
Labour (100 hours)	43.9	14.0	10.0	151.6
Capital (1000 guilders)*	403.2	265.7	56.4	2238.1
Land (hectares)	23.3	11.4	3.5	108.0

* In prices of 1980.

Source: Agricultural Economics Research Institute.

Implicit quantity indices for the output, the variable input and capital are obtained as the ratios of the value to the price index. The price indices only differ over the years, not across the farms. The quality differences in the output, the variable input, and the capital good across farms are, therefore, reflected in quantity differences across farms. Table 1.2 briefly describes the data. Clearly, there are large differences between farms in the amount of output and inputs.

Table 1.3 gives figures for the average dairy farm per year over the period 1970-1982. The average annual growth rate of output on the average farm in the sample is equal to 8.1%. The herd size on the dairy farms increased substantially and there was also an increase in the milk yield per cow. The average annual growth rate of the variable input on the average farm is equal to 9.2%. The use of concentrated feed increased because: the number of cows increased, the feed intake per cow increased, and there was a transition from feeding roughage to concentrates. The average annual growth rate of the capital good on the average farm is equal to 8.8%. During the period 1970-1982 most of the farmers invested in a cow-cubicle shed and a milk tank. The average annual growth rate of labour on the average farm is equal to −0.7% and, on average, the farm increased the land farmed by 2.3% per annum. During the seventies fodder beet and other feed crops were replaced by green maize, especially in the south and the east of the Netherlands.

The output price, the variable input price, and the price of the capital good are defined as Törnqvist price indices of components in the output and input types. The Törnqvist index is appropriate in that it implies that the underlying aggregate function is translog (Diewert, 1976). For an explanation of how the Törnqvist price index is defined, see Appendix A. The price index used in this study is the average of the Törnqvist price index over the farms for one year. This was done because if a different price index is used per farm, the differences in prices between farms also result from differences in the quality of inputs and outputs and from differences in the composition of components. Therefore, this price index would become an endogenous variable and would contradict the assumptions made in formulating the theoretical models. There are two disadvantages to this approach:

- differences in prices which are exogenous to the farmers (e.g. regional differences in prices) are treated in the same way as quality differences;

Table 1.3 Figures for the average dairy farm per year (standard deviations in parentheses)

Year	Output[1]	Variable input[1]	Labour[2]	Capital[1]	Land[3]
1970	110.7	44.7	46.9	210.8	19.8
	(48.2)	(20.6)	(15.2)	(97.5)	(9.2)
1971	125.8	48.3	46.5	229.1	20.9
	(58.2)	(23.5)	(15.7)	(109.8)	(9.7)
1972	138.3	51.2	45.4	238.9	20.8
	(64.8)	(25.7)	(14.0)	(112.8)	(8.9)
1973	146.0	54.6	44.5	266.1	20.6
	(74.2)	(30.2)	(13.6)	(132.2)	(9.2)
1974	150.7	59.5	44.4	288.3	20.8
	(76.4)	(31.4)	(12.9)	(152.5)	(9.3)
1975	179.1	69.2	44.6	336.5	22.9
	(93.9)	(40.4)	(13.8)	(192.9)	(10.7)
1976	185.7	83.3	43.5	372.2	23.3
	(98.3)	(48.9)	(12.2)	(214.6)	(10.2)
1977	217.9	93.7	45.3	421.5	24.9
	(126.1)	(59.1)	(15.8)	(253.1)	(12.5)
1978	235.9	103.0	43.9	461.9	24.5
	(129.8)	(63.2)	(14.4)	(259.9)	(11.3)
1979	240.1	113.4	42.6	484.8	23.9
	(144.4)	(75.3)	(14.2)	(292.8)	(12.0)
1980	248.2	112.6	41.8	518.2	24.1
	(144.8)	(70.6)	(13.4)	(302.6)	(12.3)
1981	265.6	116.8	42.1	548.8	24.7
	(156.7)	(72.7)	(13.3)	(306.1)	(12.9)
1982	282.4	129.2	42.9	579.9	25.9
	(178.9)	(86.9)	(13.9)	(350.3)	(14.4)

[1] 1000 guilders, in prices of 1980. [2] 100 hours. [3] 100 hectares.

- the prices only differ over the years. The sample spanned the period 1970-1982, so we have thirteen observations of the prices.

In the dynamic models (Chapters 5 and 6) capital costs is an important variable. The costs of capital are composed of interest costs and depreciation costs. Therefore, these costs depend on the prices of buildings, livestock, and machinery; the discount rate; and the depreciation rates of the different components of the capital good. The prices of buildings and machinery were corrected for investment subsidies. The Dutch government increased the investment subsidies substantially in 1978. For more details, see Appendix A.

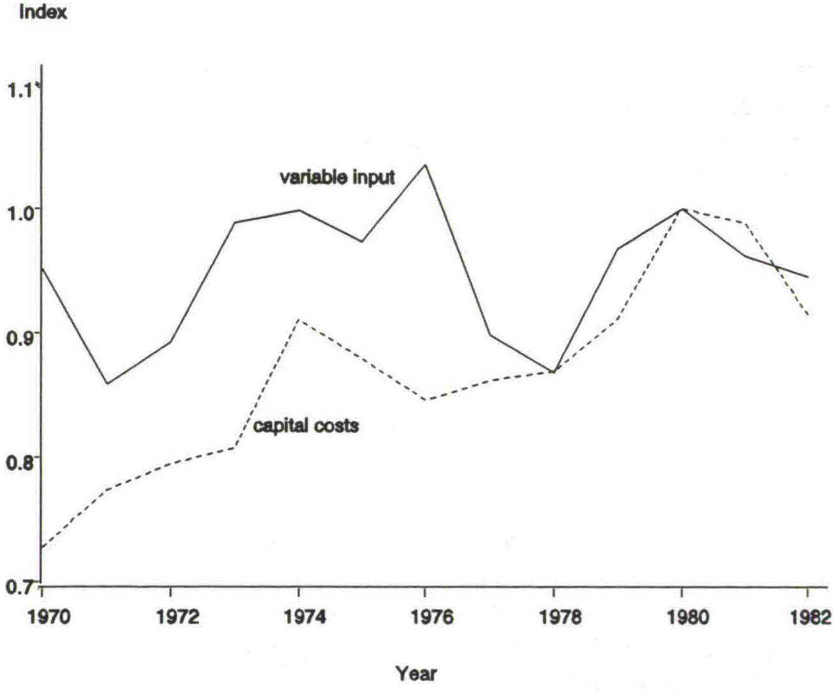

Figure 1.1 Price indices of the variable input and capital costs, normalized by the output price.

Normalized prices were used in the models. Figure 1.1 gives an overview of the path of the price of the variable input and capital costs, both normalized by the price of the output. It shows that there are important fluctuations in the normalized prices over time.

CHAPTER 2

PRODUCTION TECHNOLOGY

Two models of profit-maximizing farms are developed using the duality that exists between the normalized profit function and the production function. Some production factors are fixed in the short-run. The specification used is the translog form with variable intercepts. The equations are estimated with an incomplete panel using a SUR and 3SLS estimation method. The theoretical framework fits the data well.

Assumptions often made about the production technology are tested. Linear homogeneity and Hicks' neutrality are rejected by both models. The production and substitution elasticities calculated by both models do not differ significantly. Therefore, using data from dairy farms in the Netherlands the primal and dual models perform similarly.

2.1 Introduction

Production economics has a long history in agricultural economics. The production technology must be described if the effects of agricultural policies on prices and quantities of inputs and outputs are to be analyzed. A production function framework has often been used for this description; see, for example, Heady and Dillon (1961). During the 1970s and 1980s the profit and cost function approach gained popularity as a tool for estimating elasticities of prices (Binswanger, 1974; Elhorst, 1986; McKay et al., 1982; Higgins, 1986). This surge of popularity can be attributed to the widespread application of duality theory to economic analysis and the concomitant development of the flexible functional forms.

Given a well behaved profit function or cost function, duality theory ensures that there is a well behaved technology corresponding to the profit function or the cost function. From the standpoint of theory it is a matter of indifference as to which approach is used to measure the properties of technology. But deciding whether to focus on the primal problem and specify a production function, or to focus on the dual problem and specify a cost or a profit function involves choosing between two different representations of the technology if the functional forms used are flexible and not self-dual. Even when the functional forms used are self-dual the choice between the two representations is not a substantive one. Differences in the references about the elasticity of substitution which emerge from the two models arise because of differences in the behaviourial implications of the stochastic specification adopted. McElroy (1987) suggested a model which allows extension of the duality relations between cost and production functions in a stochastic dimension.

Burgess (1975) compared the implications for the substitution possibilities between production factors that arose when a translog specification is imposed on the production and cost functions for the same set of data. He found that these functions had very different implications for the possibilities for substitution between factors. Appelbaum (1978) came to the same conclusions. Burgess and Appelbaum both assumed full static equilibrium and only had aggregate data available.

In this chapter, two micro-economic models were developed using the particularly convenient normalized profit function approach developed by Lau (1978). It is assumed that farm families are profit maximizers in the short-run, so that not all inputs are in full static equilibrium. The assumption of full static equilibrium of all inputs in the short-run is suspect (see Cahpter 5), and hence, so are the results obtained under this assumption. A distinctive feature of an empirical micro-economic model is the close connection between economic theory and empirical implementation. The economic theory used is formulated in terms of individual decision-making units. Having data on the individual units makes it possible to use the theory fruitfully and to test it stringently.

Annual data from dairy farms in the Netherlands over the period 1970-1982 were used for estimating the model. The availability of panel data make it possible to estimate the models with intercepts that vary over the farms. The intercept reflects e.g. managerial differences and differences in the quality of land between farms. The intercept was assumed to be fixed, because of the probable correlation between the intercept and the explanatory variables of the production, profit and share equations. To estimate a fixed effects model the data were transformed in terms of deviation from unit sample means. We will show that this transformation of the data can also be applied in the case of an incomplete panel and using a SUR or 3 SLS method of estimation.

The purpose of this chapter is to compare the description of the production technology produced by the two models. The production technology is described by the production elasticities, the substitution possibilities, the returns to scale and the bias in technology. To compare the results obtained from the primal system with those obtained from the dual system variances of the elasticities were calculated in an appropriate way.

The remainder of this chapter is organized as follows. In Section 2.2 the theory underlying this study is presented. The equations for estimating the translog functional form are presented and production and substitution elasticities and tests carried out on both models are derived. In Section 2.3 data and issues relating to the estimation of the models are discussed. The estimated parameters, elasticities and tests carried out are presented in Section 2.4. Conclusions are presented in Section 2.5.

2.2 Primal model and dual model

The basis of the methodology used in this chapter is the duality which exists between the normalized profit function and the production function. This duality is widely discussed in Lau (1978) and will be only briefly described here.

It is assumed that the objective of the farm family is the maximization of short-run profit and that the farm family is a price-taker in the output and variable input markets. Therefore, the firm is in static equilibrium with respect to the output and the variable input that is conditional on the perceived level of the remaining inputs: the fixed inputs (labour, capital, and land). Profit normalized by the output price is maximized by farm h, subject to a production constraint of production technology that depicts the relationship between inputs and output as[1]:

$$\pi_h\ (p,\ l_h,\ k_h,\ g_h,\ t) = \max_{q_h,\, v_h}\ (q_h - p\ v_h) \tag{2.1}$$

$$q_h = q_h\ (v_h,\ l_h,\ k_h,\ g_h,\ t) \tag{2.2}$$

where π is the short-run profit function normalized by the output price; p is the ratio of the price of the variable input to the price of the output; v

[1] In this study we want to describe the actual and not the optimal relationship between the inputs and the output. The production function in this study does not, therefore, reflects the production frontier function.

is the variable input; l is labour; k is capital; g is land; t is technology; and q is the output.[2] Note that the prices differ over the years but not over the farms.

The primal model starts from a production function, which has the usual properties (Lau, 1978: 135-136). The translog was chosen as the functional form, because it is flexible.

$$\log q_h = \alpha_{0h} + \sum_{i=1}^{5} \alpha_i \log x_{ih} + \tfrac{1}{2} \sum_{i=1}^{5} \sum_{j=1}^{5} \alpha_{ij} \log x_{ih} \log x_{jh} \tag{2.3}$$

where $\alpha_{ij} = \alpha_{ji}$; x_i are the inputs (with i = 1 or v (variable input), 2 or l (labour), 3 or k (capital), 4 or g (land), 5 or t (technology)).

The production function contains an intercept that varies over the farms (Mundlak, 1961). This intercept reflects managerial differences and differences in the quality of land between firms. It is assumed that the other parameters are the same for all farms.

Maximizing profits subject to the production constraint gives the marginal productivity condition for variable inputs. In share form this is:

$$\frac{p_v \; v_h}{p_q \; q_h} = \alpha_{1h} + \sum_{j=1}^{5} \alpha_{1j} \log x_{jh} \tag{2.4}$$

Because of quality and managerial differences between firms the intercept of the share equation also differs between firms. The primal model contains the two equations (2.3) and (2.4).

The normalized short-run profit function π for farm h is a function of p, l_h, k_h, g_h and t, which, for each set of values of p, l_h, k_h, g_h and t gives the maximized value of normalized (by the output price) profit. Assuming the translog specification, the normalized short-run profit function is written as:

[2] The number of the distinguished inputs have been restricted to five, because the extension to a larger number of inputs become problematic as the number of possible combinations of input pairs increases rapidly and problems of estimation and interpretation arise.

$$\log \pi_h = \beta_{0h} + \beta_1 \log p + \sum_{i=2}^{5} \beta_i \log x_{ih} + \tfrac{1}{2} \beta_{11} (\log p)^2 + \sum_{i=2}^{5} \beta_{1i} \log p \log x_{ih} + \tfrac{1}{2} \sum_{i=2}^{5} \sum_{j=2}^{5} \beta_{ij} \log x_{ih} \log x_{jh} \tag{2.5}$$

where: $\beta_{ij} = \beta_{ji}$

By Hotelling's Lemma, if we differentiate the normalized short-run profit function with respect to the normalized price, we obtain the share function for the variable input:

$$\frac{p\ v_h}{\pi_h} = -(\beta_{1h} + \beta_{11} \log p + \sum_{i=2}^{5} \beta_{1i} \log x_{ih}) \tag{2.6}$$

The dual model is composed of the normalized short-run profit function and the related demand function for variable inputs. If the normalized variable profit function satisfies certain conditions of regularity (Lau, 1978), it is the dual of the production function and its parameters contain sufficient information to describe the farm's production technology at profit-maximizing points in the set of production possibilities.

Here, the farm's technology is described by production elasticities, scale and substitution effects, the rate of technical change and the bias in technical change. These effects can easily be calculated for the primal model. The production elasticity, using the production function, of input i (e_i) is (the index h has been removed to improve the readability of the formulae):

$$e_i = \frac{\partial \log q}{\partial \log x_i} = \alpha_i + \sum_{j=1}^{5} \alpha_{ij} \log x_j \tag{2.7}$$

The two best known partial elasticities of substitution are the direct elasticity of substitution (DES) and the Allen elasticity of substitution (AES) (Nadiri, 1982: 443). The DES gives information about the convexity of an isoquant. It is the percentage change in the ratio of inputs divided by the percentage change in the marginal products. The AES is a measure of change in the firm's demand for factor j, given a change in the price of factor i; all other prices remain constant. Assuming profit-maximizing behaviour in the short-term results in most of the production factors being fixed; hence no exogenous prices are available for these factors. This means that AES is difficult to interpret, and therefore it was decided to use the DES. The direct substitution elasticity between inputs i and j is:

$$s_{ij} = \frac{e_i^2\ e_j + e_i\ e_j^2}{(\alpha_{ii} - e_i)\ e_j^2 + (\alpha_{jj} - e_j)\ e_i^2 - 2\ \alpha_{ij}\ e_i\ e_j} \tag{2.8}$$

The production and substitution elasticities can also be calculated for the model that is based on the normalized short-run profit function, by using a set of relations between the production and the normalized short-run profit function (Lau, 1978:146-156). The production elasticity of the variable input is:

$$\frac{\partial \log q}{\partial \log v} = -\frac{f_p}{1 - f_p} \tag{2.9}$$

$$\text{where: } f_p = \frac{\partial \log \pi}{\partial \log p} = \beta_1 + \beta_{11} \log p + \sum_{i=2}^{5} \beta_{1i} \log x_i$$

The first derivative of the fixed input of the production function is equal to the first derivative of the fixed input of the normalized short-run profit function. Therefore, using Hotelling's Lemma the production elasticity of fixed input i (e_i) is:

$$e_i = \frac{\partial \log q}{\partial \log x_i} = \frac{f_i}{1 - f_p} \tag{2.10}$$

$$\text{where: } f_i = \frac{\partial \log \pi}{\partial \log x_i} = \beta_i + \beta_{1i} \log p + \sum_{j=2}^{5} \beta_{ij} \log x_j$$

The substitution elasticity between two fixed inputs can be calculated on the basis of the normalized short-run profit function in the same way as using the production function:

$$s_{ij} = \frac{f_i^2\, f_j + f_i\, f_j^2}{(\beta_{ii} - f_i)\, f_j^2 + (\beta_{jj} - f_j)\, f_i^2 - 2\, \beta_{ij}\, f_i\, f_j} \quad ; i,j > 1 \tag{2.11}$$

This similarity arises because the first and second derivatives of the fixed inputs of the production function are equal to the first and second derivatives of the fixed inputs of the normalized short-run profit function. It is not so easy to calculate the substitution elasticity between a variable input and a fixed input. Using the relationship between the Hessian matrices of the production function and the normalized short-run profit function (Lau,1978:149) the following formula was derived:

$$s_{1j} = \frac{(f_p - f_j)\,(f_p^2 - f_p + \beta_{11})}{-f_j^2 f_p + 2 f_p f_j (\beta_{1j} + f_j f_p) + f_p (f_j^2 - f_j + \beta_{jj})(f_p^2 - f_p + \beta_{11})} \tag{2.12}$$

Before calculating production and substitution elasticities, the neoclassical production theory will be tested in several ways. The parameter vector has to satisfy certain restrictions that ensure it is consistent with the underlying theory. Testable conditions are: the normalized short-run profit function is convex in price; decreasing in price and increasing in fixed inputs.[3] It is also assumed that the production function has certain properties: concave in the variable input; increasing in the variable input and increasing in fixed inputs.

Two other tests are carried out, in accordance with the production technology: constant returns to scale and Hicks' neutrality for technical change. Tests on scale effects for the dual model can be done using the following theorem (Lau, 1978: 164): a production function is linearly homogeneous in all inputs, variable and fixed, if and only if the normalized short-run profit function is linearly homogeneous in the fixed inputs. A normalized short-run profit function is Hicks' neutral when it is separable in technology. This implies Hicks' neutrality of the production function if the normalized short-run profit function is homothetic or additively separable in t (Lau, 1978: 202). The tests are summarized in Table 2.1.

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[3] The profit function is normalized by the price of the output, to ensure that the profit function is linear homogeneous in prices.

Table 2.1 Tests carried out on the primal model and the dual model

Primal model
Increasing in inputs: $e_i \geq 0$, $i = v,l,k,g$
Concave in the variable input[4]: $e_v^2 - e_v + \alpha_{vv} \leq 0$
Linear homogeneity: $\sum_{i=1}^{4} \alpha_i = 1$; $\sum_{i=1}^{4} \alpha_{ij} = 0$, $j = v,l,k,g,t$
Hicks' neutrality: $\alpha_{jt} = 0$, $j = v,l,k,g$
Dual model
Decreasing in price: $f_p \leq 0$
Increasing in fixed inputs: $f_i \geq 0$, $i = l,k,g$
Convex in the price: $f_p^2 - f_p + \beta_{pp} \geq 0$
Linear homogeneity: $\sum_{i=2}^{4} \beta_i = 1$; $\sum_{i=2}^{4} \beta_{ij} = 0$, $j = p,l,k,g,t$
Hicks' neutrality: $\beta_{jt} = 0$, $j = p,l,k,g$

2.3 Data and estimation

The data used are from a sample of Dutch farms that keep accounts of their farming for the Agricultural Economics Research Institute. Annual data from dairy farms over the period 1970-1982 were used for estimation of the model. The farms usually remain in the panel for about five years, the data set forms an unbalanced panel. In total there were 2196

[4] The production function is concave in the variable input when the second derivative of the variable input is negative:

$$\frac{\partial^2 q}{\partial v^2} = \frac{q}{v^2} \left(e_v^2 - e_v + \alpha_{vv}\right) \leq 0$$

Thus when $e_v^2 - e_v + \alpha_{vv}$ is negative, this condition is fulfilled. The advantage of using $e_v^2 - e_v + \alpha_{vv}$ is that the standard error of this term can easily be calculated.

observations and 568 different farms in the sample. One output and four inputs were included in the production function. The inputs are variable input, labour, capital, and land. Implicit quantity index for the output, the variable input and capital were obtained as the ratio of the value to the Törnqvist price index. The Törnqvist price index only differs over the years, not over the farms. The quality differences in the output, the variable input, and the capital good across the farms are, therefore, reflected in quantity differences across the farms. For example, the amount of capital is the value of the capital stock on the farm divided by a uniform price index per year. The value of the capital stock takes into account that there are differences in the quality of the buildings, livestock and machinery across the farms. Therefore, the amount of the capital stock reflects quality differences across the farms. No adjustment has taken place for differences in the quality of labour and land across farms. To take these differences into account the intercepts of the estimated equations vary over the farms. Normalized profit is defined as the value of output minus the value of variable input divided by the Törnqvist price index of output. The relative price used in the normalized short-run profit function is the ratio of the Törnqvist price indices of variable input and output. The prices of machinery and building capital were corrected for investment subsidies. For a complete description of the data, see Section 1.3 and Appendix A.

Both the production and the profits of the dairy sector are strongly influenced by the weather. It is possible for the production volume to change over time without changes in inputs. Therefore a weather index with parameter α_w was added to the production function and a weather index with parameter β_w was added to the short-run profit function. A meteorological model was used to calculate the weather indices. The climatic factors on which the index depends are rainfall, average temperature and hours of sunshine (Oskam and Reinhard, 1992).

The two models developed describe the farm's production technology at profit-maximizing points. These models are the production function and its corresponding share equation, and the normalized short-run profit function and its corresponding share equation. Additive error terms are added to these equations because:

- farmers are profit maximizers but they will not always succeed in choosing levels of output and inputs that will lead to a maximum level of profit;
- the two functional forms distinguished are approximations of the true underlying production and short-run profit functions.

The cross-equation symmetry restrictions, the possibility that the error terms of the production function and share equation may be correlated and the endogeneity of the variable input makes 3SLS (Judge et al., 1985: 599) an appropriate estimation technique for the primal model. Endogenous variables are: log q, log v, log v log x_j (j = v,l,k,g,t) and $p_v v/p_q q$. Instruments used are the exogenous variables in the model, second and cubic terms of the exogenous variables, age of the farmer and farm size, all in terms of deviations from unit sample means.[5] SUR (Judge et al., 1985: 467) is an appropriate technique for estimating the dual model, because of the cross-equation symmetry restrictions and the possibility that the error terms of the profit equation and the related share equation may be correlated. Endogenous variables are log π and pv/π. The models are estimated using the computer program package SAS.

The availability of panel data makes it possible to estimate the models that are developed with variable intercepts. The variable intercept is assumed to be fixed, because of the probable correlation between the variable intercepts and the explanatory variables of the production, profit and share equations. Therefore the random-effects approach in which the random effects are assumed not to correlate with explanatory variables would generate biased estimates.[6] We show in Appendix B that the common transformation of the data for a fixed effects model (Judge et al., 1985: 521) can also be applied to an incomplete panel and using a SUR or 3SLS estimation method. This was not unexpected: Cornwell and Schmidt (1987) showed that in systems of seemingly unrelated regressions and in systems of simultaneous equations maximum likelihood estimation of a fixed effects model on the transformed data is consistent for all parameters except the intercept.

According to neoclassical theory, the primal and dual models give identical descriptions of the production technology. In practice, however, they differ in stochastic specification and, unless a self-dual form is used, in functional form. There is also no generalization of the translog function specification from which the translog production function and the translog normalized short-run profit function can be derived by imposing restric-

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[5] The results of the estimation are sensitive to the instruments used. When only the exogenous variables in the model are used, the estimated production function is not convex in the variable input.

[6] In Chapter 3 a system of factor demand and output supply is estimated, using the same dataset. A Hausman test rejects the assumption that the individual effects are independent of the regressors.

tions on parameters. A rigorous and direct test for the equality of the parameters in the primal and dual models cannot, therefore, be carried out. Therefore, an indirect method is required. As an alternative and indirect method, we will compare the results obtained from the primal system with those obtained from the dual system. More specifically, production and substitution elasticities obtained from the two models are compared, to ascertain the extent to which the two models are equivalent in practice. To do this, variances of these elasticities have to be calculated in an appropriate way by[7]:

$$S_e = \left[\frac{\partial e}{\partial c}\right]' \Omega \left[\frac{\partial e}{\partial c}\right] \tag{2.13}$$

where c is a vector of the parameters of the production or normalized short-run profit function and Ω is the covariance matrix of the estimators of these parameters.[8]

2.4 Results

The parameters of the two models estimated are presented in Table 2.2. The first three columns correspond to the primal model, equations (2.3) and (2.4). The fourth column up to the sixth column correspond to the dual model, equations (2.5) and (2.6). The R^2 of the production function is 0.99; the R^2 of the related share equation is 0.80. The R^2 of the normalized profit function is 0.96; the R^2 of the related share equation is 0.60. There is no important difference in the significance of the parameters between the two models. The significance of many of the parameters is low, a known disadvantage of the fixed effects model. However, care should be taken not to base any far-reaching conclusion on the significance or non-significance of parameters. The model is non-linear in

[7] See Rao (1973: 382-389). To calculate the standard errors of the elasticities, deviations from equations (2.7), (2.8), (2.9), (2.10), (2.11) and (2.12) are worked out. The resulting equations are complex and are not presented in the text. No account is taken of the stochastic nature of the variable input in equations (2.7) and (2.8).

[8] This variance is based on the asymptotic distribution of the estimator of the elasticities. The finite sample distribution of this estimator is more difficult to obtain (Anderson and Thursby, 1986).

variables, so that one cannot generally associate a parameter with a particular variable, as in a linear model. This is why elasticities of production and substitution elasticities were calculated.

Table 2.2 Parameter estimates of the primal and the dual model*

Primal model			Dual model		
Parameter	Coefficient	Standard error	Parameter	Coefficient	Standard error
α_v	0.38	0.15	β_p	-3.65	0.58
α_l	0.43	0.30	β_l	1.44	0.52
α_k	0.39	0.31	β_k	1.26	0.55
α_g	0.48	0.31	β_g	0.18	0.65
α_t	-0.03	0.03	β_t	-0.11	0.05
α_{vv}	0.19	0.01	β_{pp}	-1.44	0.09
α_{vl}	-0.06	0.01	β_{pl}	0.06	0.05
α_{vk}	-0.05	0.01	β_{pk}	-0.09	0.03
α_{vg}	-0.11	0.01	β_{pg}	0.41	0.06
α_{vt}	-0.003	0.001	β_{pt}	-0.007	0.004
α_{ll}	-0.004	0.05	β_{ll}	-0.05	0.08
α_1	0.02	0.03	β_{lk}	-0.01	0.05
α_{lg}	0.01	0.04	β_{lg}	-0.09	0.07
α_{lt}	0.002	0.003	β_{lt}	0.01	0.01
α_{kk}	-0.01	0.04	β_{kk}	-0.09	0.06
α_{kg}	0.03	0.03	β_{kg}	0.02	0.06
α_{kt}	0.01	0.003	β_{kt}	0.02	0.005
α_{gg}	0.09	0.05	β_{gg}	0.12	0.09
α_{gt}	-0.003	0.003	β_{gt}	-0.01	0.006
α_{tt}	-0.002	0.001	β_{tt}	-0.01	0.001
α_w	0.19	0.03	β_w	0.28	0.05

* The subscripts v, p, l, k, g, t, w refer to variable input, normalized price, labour, capital, land, technology, and weather, respectively.

Before calculating these elasticities it is important to test the basic assumption underlying the methodology using in this study: i.e. that farmers are profit-maximizers. For testing the assumption of monotonicity, elasticities for both models were calculated using the estimated parameters. As can be concluded from Table 2.3, the production function increases in the variable input and the fixed inputs. The normalized short-run profit function decreases in price and increases in the fixed inputs. Therefore, these assumptions in the models are not rejected at the sample mean.

Table 2.3 Test of the monotonicity assumption, elasticities at the sample mean (standard errors in parentheses)

	Variable input	Relative price	Labour	Capital	Land
Primal model	0.60		0.09	0.09	0.30
	(0.03)		(0.02)	(0.02)	(0.03)
Dual model		-1.09	0.20	0.29	0.52
		(0.05)	(0.03)	(0.02)	(0.04)

A report on the concavity/convexity assumption can be found in Table 2.4, the formulas used can be found in Table 2.1. The translog production function is concave in the variable input for 97% of the observations. The concavity assumption cannot be rejected at the sample mean, because the second derivative of the production function with respect to the variable input is smaller than 1.65. The short-run profit function is convex in the normalized price for 96% of the observations. The convexity assumption cannot be rejected at the sample mean, because the second derivative of the normalized profit function with respect to the normalized price is greater than -1.65. The results of the tests indicate that profit maximization is maintained in the two models.

Now, the two model's descriptions of the production technology are compared. First, the production technology was tested on linear homogeneity and Hicks' neutrality. Both assumptions are rejected by both models. The linear homogeneity assumption was tested using the chi-square test developed by Gallant and Jorgenson (1979). If the sample agrees with the null hypothesis the chi-square value will be near zero and if the null hypothesis is rejected the chi-square value will be large. The

Table 2.4 Tests of the concavity/convexity assumption, linear homogeneity and Hicks' neutrality at the sample mean

	Primal model	Critical value (5% level)	Dual model	Critical value (5% level)
Concavity/ convexity (t-value)	-3.33	1.65	5.93	-1.65
Linear homogeneity (χ^2 value)	123.94	12.59	77.03	12.59
Hicks' neutrality (F value)	4.11	2.37	4.73	2.37
Concavity / convexity (%)	97		96	

assumption of Hicks' neutrality is fulfilled if some of the parameters equal zero, see Table 2.1. Therefore, the F test is an appropriate one.

Next, production and substitution elasticities obtained from the primal model and the dual model will be compared. The significance of the differences between the elasticities of both models was calculated, assuming there are no correlations between these elasticities. The variance of the difference between elasticities of the two models is, therefore, equal to the sum of the variances of the two elasticities.

The production elasticities for the primal model were calculated with equation (2.7); equations (2.9) and (2.10) were used for the dual model. The differences between the production elasticities obtained using the primal model and the dual model are not statistically significant at the 5% level. The standard errors of the production elasticities estimated with the dual model are larger than the standard errors of the production elasticities of the primal model. This is probably because the production elasticities calculated using the dual model depend more on estimated parameters than when the primal model is used. (Compare equations (2.7) and (2.9) and (2.10)). Therefore the production elasticities can be calculated more accurately using the primal model.

Table 2.5 Production elasticities at the sample mean (standard errors in parentheses)

	Variable input	Labour	Capital	Land	Techn. change
Primal model	0.60	0.09	0.09	0.30	0.006
	(0.03)	(0.02)	(0.02)	(0.03)	(0.002)
Dual model	0.52	0.09	0.14	0.25	0.011
	(0.13)	(0.25)	(0.27)	(0.37)	(0.003)

It can be concluded from Table 2.5 that the production elasticity of the variable input is large, an increase of this input (remaining the other inputs constant) results in a large increase of the production. An increase of capital or labour (remaining the other inputs constant) does not result in a large increase of the production. The production elasticity of land is larger than the production elasticities of labour and capital: the production factor land is scarce. The returns to scale can be calculated by adding up the production elasticities (Chambers, 1988: 24). As can be concluded from Table 2.5 the elasticitiy of scale is 1.08 for the primal model and 1.00 for the dual model, there are slightly increasing returns to scale at the sample mean. This result for the dual model differs from the result in Table 2.4, because in Table 2.4 linear homogeneity is tested for the complete sample by imposing restrictions on the parameters.

The substitution elasticities based on the two models are compared in Table 2.6. To obtain these elasticities equation (2.8) was used for the primal model and equations (2.11) and (2.12) were used for the dual model. The differences between the substitution elasticities of the primal and dual model are not statistically significant at the 5% level.

The substitution possibilities of the factors of production for the dairy sector are good when the variable input is involved. The fixed inputs are more difficult to substitute. The substitution elasticities obtained by both models are characterized by large standard errors. Especially the standard errors of the dual model when the variable input is involved are very large, this is probably because these substitution elasticities depend on many estimated parameters (equation (2.12)).

The production elasticities and the substitution elasticities are not compared with results of other studies, because there is hardly any study using flexible functional forms which calculate these elasticities. As already noted by Colman (1983) agricultural economists have during the

1970s and 1980s exhibited a preference for pursuing the dual route and calculate only the price elasticities.

Table 2.6 Substitution elasticities based on the two models at the sample mean. Primal model upper triangular matrix, dual model lower triangular matrix (standard errors in parentheses)

	Variable input	Labour	Capital	Land
Variable input		-1.19 (0.66)	-1.07 (0.41)	-2.24 (0.59)
Labour	-3.54 (3.34)		-0.77 (0.32)	-0.99 (0.52)
Capital	-1.88 (1.64)	-0.83 (0.27)		-0.85 (0.33)
Land	-2.28 (1.86)	-1.18 (0.62)	-0.86 (0.23)	

2.5 Conclusions

Two micro-economic models were developed to describe the farm's production technology at short-run profit-maximizing points. They are based on the duality that exists between the production function and the normalized short-run profit function. The main conclusions obtained from the study are:

(a) The models seem to describe appropriately the production technology of the dairy farms. This is supported in that the restrictions implied by neoclassical production theory are corroborated by the estimated equations and in that the elasticity estimates are reasonable.

(b) To estimate a fixed effects model, the data were transformed in terms of deviation from unit sample means. This transformation of the data can also be applied in the case of an incomplete panel and using a SUR or 3SLS method of estimation.

(c) The production technology of the dairy farms in the Netherlands is not Hicks' neutral and, according to both models, cannot be characterized by constant returns to scale.

(d) The differences between production and substitution elasticities calculated by both models are not significant. But the production elasticities can be calculated more accurately using the primal model. The substitution possibilities of the factors of production for the dairy sector are good when the variable input is involved. The fixed inputs are more difficult to substitute. The substitution elasticities obtained by both models are not very accurate, especially the dual model generates very large standard errors when the variable input is involved.

(e) The main conclusion to be drawn from this chapter is that when a flexible functional form is used to describe the production technology, the primal and dual approaches are not significantly different. This is in contrast with the conclusion reached by Burgess (1975) and Appelbaum (1978), who, however, assume full static equilibrium and use aggregate data.

CHAPTER 3

SUPPLY RESPONSE AND INPUT DEMAND

A system of factor demand and output supply is estimated using an incomplete panel of Dutch dairy farms. The intercepts of the two equations vary over the farms, reflecting differences in quality of labour and land. Comparison of fixed effects estimates and random effects estimates using a Hausman test favours the fixed effects model. The theoretical framework fits the data well. The own-price elasticity of the output supply is small, 0.10. The effect of land on the output supply mainly lies in the scarcity of land in the Dutch dairy sector. On the contrary the effect of capital on the output supply is mainly caused by the influence of capital on the demand for feed.

3.1 Introduction

In agricultural economics, the responsiveness of farmers to output and input price changes are of central concern. The price elasticities of outputs and inputs determine not only the possibilities of the traditional agricultural policies, but determine how far levies and subsidies can be used in environmental policies.

Using the results of Chapter 2, starting point in this chapter is the dual approach. Duality theory provides a useful framework for estimating the short-run price elasticities of the output and the variable input. It is assumed that the farm's objective is to maximize short-run profits. This assumption is also made in a dynamic context, with a farm family as a starting point who maximizes the expected present value of income over an infinite horizon with respect to the inputs. This farm's objective can be viewed as first having to maximize short-run profits (resulting in a short-run profit function) and then maximizing the present value of its long-run expected profits. Short-run profit, output supply and variable input demand are, therefore, conditional upon a fixed level of capital stock, labour, and land. In the intermediate-run the level of capital stock will change, when prices change. This results in a change of output and variable input in the intermediate-run and long-run (see Chapter 5). Therefore, the elasticities of capital in the supply function of the output and in the demand function for the variable input are of special interest in a short-run model. The elasticity of labour in a short-run model is also of interest, because in models where labour is not fixed it is assumed that short-run profit is maximized, given the volume of family labour (see Chapter 4).

Short-run models using the duality approach have been estimated in many studies in agricultural economics (e.g. Higgins (1986), Burrell (1989), McKay et al. (1982)). Burrell and McKay had only aggregate data available, but the economic theory used is formulated in terms of individual decision-making units. Having data on the individual units, it is possible to use the theory more fruitfully and to test it stringently. Higgins had data available at the farm level, but he had only a cross-section of farms and because of this he had to use the differences in prices between farms. These differences, however, result mainly from differences in the quality and the composition of inputs and outputs between farms. Therefore, the prices in a cross-section become endogenous.

In this study annual data from Dutch dairy farms over the period 1970-1982 were used for estimating the model. The availability of panel data made it possible to estimate the model with farm varying intercepts. The farm intercept reflects quality differences in the inputs between farms and consist mainly of managerial differences and differences in the quality of land. In the fixed effects model the intercepts are treated as fixed parameters, whereas in the random effects model the intercepts are treated as a sample of random drawings from a population, and they become part of the model's disturbance term. A priori, it is not clear which of the two models should be used. Therefore, both models will be estimated and the assumptions made will be tested by a Hausman test (1978).

To recapitulate, in this chapter a short-run model was developed and estimated with as ultimate goal estimation of short-run elasticities of prices and fixed inputs. The model differs from previous ones in that panel data were explicitly used.

The chapter is organized as follows. In Section 3.2 the model is presented. The equations for estimating the output supply function and the demand function for the variable input are derived. In Section 3.3 the fixed effects estimation procedure and the random effects estimation procedure are discussed. The data used are described in Section 3.4. The estimated parameters, elasticities, and tests carried out are presented in section 3.5. Conclusions are drawn in Section 3.6.

3.2 The model

The theoretical background of the model is the neoclassical production theory. It is assumed that the objective of the farm family is the maximization of short-run profit and that the farm family is a price-taker in the output and variable input markets. Therefore, the firm is in static equilibrium with respect to output and a subset of inputs (the variable input) that is conditional on the level of the remaining inputs (fixed inputs). Profit, normalized by the output price, is maximized by farm h, subject to a production technology governing the relationship between inputs and farm output as:

$$\pi_h\,(p, l_h, k_h, g_h, t) = \max_{q_h, v_h}\,(q_h - p\,v_h) \tag{3.1}$$

subject to:

$$q_h = q_h(\,v_h, l_h, k_h, g_h, t) \tag{3.2}$$

where π is the profit function normalized by the output price; p is the ratio of the price of the variable input to the price of the output; v is the variable input; l is labour; k is capital; g is land; t is technology; and q is the output. Note that the technology level and the prices differ over the years but not over the farms.

According to duality theory[1], the optimizing behaviour of farmers constrained by technology can equivalently be represented by the profit function π, given in equation (3.1), see Chapter 2. If the profit function satisfies certain regularity conditions, it is dual to the production function and its parameters contain sufficient information to describe the farm's production technology at profit maximizing points in the set of production possibilities. Testable conditions of regularity are: the profit function is decreasing in the price of the input; increasing in the price of the output; convex in all prices; linearly homogeneous in prices and increasing in fixed inputs. The profit function is normalized by the price of the output, to ensure that the profit function is linear homogeneous in prices.

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[1] This duality is widely discussed in the literature, for example Chambers (1988).

For the empirical analysis, a flexible functional form is used for the profit function, the quadratic. The normalized profit function is written as:[2]

$$\pi_h = \alpha_{0h} + s_{0h} - (\alpha_{1h} + s_{1h})\, p + \tfrac{1}{2}\, \alpha_2\, p^2$$

$$- \sum_{i=1}^{4} \beta_i\, p\, x_{ih} + \sum_{i=1}^{4} \gamma_i\, x_{ih} \qquad (3.3)$$

where x_i are the fixed inputs and technology (with i = 1 or l (labour), 2 or k (capital), 3 or g (land), 4 or t (technology)); s_{0h} and s_{1h} are exogenous stochastic shocks. The s_{0h} contains general stochastic shocks influencing the profit level. These shocks can be caused by (i) measurement errors, (ii) differences between the quadratic functional form and the true underlying profit function and (iii) optimization errors. The s_{1h} is a stochastic process influencing the relation between the price and the profit. This can be caused by lack of information. Usually stochastic components are added to the equations, just before the estimation process will be started. The advantage of defining these stochastic components in the profit function is that the assumptions made with respect to the stochastic components become apparent. The stochastic shocks are specified in such a way that the resulting input demand and output supply equations are linear in these stochastic shocks.

By Hotelling's Lemma, when we differentiate the profit function with respect to the price p, we obtain the demand function for the variable input.

$$v_h = \alpha_{1h} - \alpha_2\, p + \beta_1\, l_h + \beta_2\, k_h + \beta_3\, g_h + \beta_4\, t + s_{1h} \qquad (3.4)$$

The optimal output for a normalized profit function is, using the definition of the normalized profit ($\pi_h = q_h - p\, v_h$):

$$q_h = \pi_h - p\, \partial\, \pi_h / \partial\, p \qquad (3.5)$$

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[2] There are no second order terms for fixed inputs in the profit function, because taking into account second order terms for fixed inputs result in a supply function containing second order terms for fixed inputs and a demand function without second order terms for fixed inputs.

The output supply function, therefore, looks as follows:

$$q_h = \alpha_{0h} - \tfrac{1}{2} \alpha_2 p^2 + \gamma_1 l_h + \gamma_2 k_h + \gamma_3 g_h + \gamma_4 t + s_{0h} \tag{3.6}$$

As can be concluded from equations (3.4) and (3.6):
- the own-price elasticity of the demand for the variable input is negative and the own-price elasticity of the output is positive, if $\alpha_2 > 0$; this condition is fulfilled when the profit function is convex in the price. It is an advantage of the quadratic functional form that convexity reduces to a simple constraint;
- the functions are homogeneous of degree zero in prices, because p is the ratio of the price of the variable input to the price of the output;
- the symmetry condition is fulfilled:

$$\partial v_h / \partial p_q = - \partial q_h / \partial p_v = \alpha_2 p_v / p_q^2$$

The convexity restriction ($\alpha_2 > 0$) and also the symmetry condition will be tested. The homogeneity restriction is not tested, because this is not possible in a linear framework. There is no restriction to ensure homogeneity when the price of the output and the price of the variable input are treated as separate variables.

In the demand function for the variable input and the output supply function, the intercept varies over the farms. This intercept is assumed to capture quality differences in the inputs between farms, consisting mainly of managerial differences and differences in the quality of land. The appropriate estimation procedure of the equations (3.4) and (3.6) depends on whether the intercept is assumed to be random or fixed. If the intercept is fixed, equations (3.4) and (3.6) are called the fixed effect model or the dummy variable model, while if the intercept is random, equations (3.4) and (3.6) are called the random effects model or the error components model.

3.3 Fixed effects and random effects estimation procedures

In this section the fixed effects model, the random effects model and the relevant issues for choice between the two models are discussed. Attention will be paid to the way in which these models can be estimated when only a incomplete panel is available, i.e. when not all cross-sectional units are observed in all periods.

Only the assumptions made and the way these models can be estimated are described. For an extensive discussion, see Hsiao (1986) or Judge et al. (1988).

Consider the following regression model with a fixed effect:

$$y_{ht} = \alpha_h + z_{ht}'\beta + e_{ht} \quad , \quad h = 1....H \; , \quad t = 1.....T \tag{3.7}$$

where y is the dependent variable; z is a K vector of explanatory variables; α_h is the fixed effect of farm h representing the effects of those variables peculiar to the hth individual in the same fashion over time; β is a K vector of parameters; e is the error term which represents the effects of the omitted variables that are peculiar to both the individual units and time periods; H is the number of individuals and T is the number of time-series observations. We assume that e_{ht} can be characterized by an independently identically distributed random variable with mean zero and variance σ_e^2. This model can be written as

$$y_{ht} = \sum_{j=1}^{H} \alpha_j D_{jt} + \sum_{k=1}^{K} \beta_k z_{kht} + e_{ht} \tag{3.8}$$

where the D_{jt} are dummy variables, $D_{jt} = 1$ if $j=h$ and $D_{jt} = 0$ if $j \neq h$. Thus, there is a dummy variable corresponding to each individual, and the dummy variable that corresponds to individual j, will take the value unity for observations on individual j but will be 0 for observations on other individuals. When the number of individuals H is small, equation (3.8) can be estimated straightforward by OLS. When, for instance, data relates to several countries (for example the members of the European Community) and covers different years, equation (3.8) is a model of interest.

When H is large, equation (3.8) becomes difficult to estimate. The problem can be overcome by premultiplying the observations on each individual by a matrix P. The matrix $P = I_T - j_T j_T'/T$, where $j_T = (1\ 1\ ....\ 1)'$ is a T vector of ones, and I_T is the identity matrix TxT. This matrix transforms the observations on each individual so that they are in terms of deviations around the mean for that individual. Applying this transformation to equation (3.8) gives:

$$(y_{ht} - \bar{y}_{h.}) = \sum_{k=1}^{K} \beta_k \, (z_{kht} - \bar{z}_{kh.}) + (e_{ht} - \bar{e}_{h.}) \tag{3.9}$$

where $\bar{y}_{h.} = \sum_{t=1}^{T} y_{ht}$, $\bar{z}_{kh.} = \sum_{t=1}^{T} z_{kht}$, $\bar{e}_{h.} = \sum_{t=1}^{T} e_{ht}$

An estimator of the β vector can be obtained by applying OLS to equation (3.9). The standard errors should be corrected for the loss of degrees of freedom, the calculated standard errors should be multiplied by $[(N - K)/(N - H - K)]^{½}$, where N is the total numbers of observations, $N = H \cdot T$. The $R^2 = 1 - SSE/SST$, where SSE is the error sum of squares and SST is the total sum of squares. The SSE is the same for equation (3.8) and equation (3.9). But the SST differs of course between the equations (3.8) and (3.9). To calculate the R^2 one should take the SST of equation (3.8). Of course it is more convenient to work with the corrected R^2. In that case one should also correct for the loss in degrees of freedom.

When only an incomplete panel is available, the transformation matrix P has to be replaced by a more complicated matrix, but the effect remains the same; the observed variables for each individual are transformed so that they are in terms of deviations of the mean value of that variable for that individual. (Wansbeek and Kapteyn, 1989). The same estimation procedure can be applied, therefore, when a panel is incomplete.

The fixed effects model can be tested on the assumption that all the individuals have different intercepts. If they are all the same and the other assumptions of the model continue to hold, then there is no basis for differentiating the time-series cross-sectional nature of the data, and, for estimation purposes, the data can be treated as one sample of N observations. An appropriate test is the F-test with associated test statistic:

$$F = \frac{(SSE_r - SSE_u) \,/\, (H - 1)}{SSE_u \,/\, (N - H - K)} \tag{3.10}$$

where SSE_r is the sum of squared residuals obtained by an estimation of equation (3.7) with α_h equal for all individuals; SSE_u is the sum of squared residuals obtained by OLS on equation (3.9). Under the null hypothesis that all the fixed effects are equal the statistic in (3.10) follows an F distribution with [(H - 1),(N - H - K)] degrees of freedom and the test is implemented in the usual way.

In the random effects model, the α_h are assumed to be random draws from a distribution with mean α:

$$\alpha_h = \alpha + u_h \tag{3.11}$$

where u_h can be characterized by an independently, identically distributed, random variable with mean zero and variance σ_u^2. Furthermore, it is assumed that the u_h are uncorrelated with the e_{ht}, uncorrelated with the explanatory variables z and $E(u_i u_j) = 0$, $i \neq j$. Equation (3.7) now becomes:

$$y_{ht} = \alpha + z_{ht}'\beta + u_h + e_{ht} \tag{3.12}$$

which can be written in matrix notation for the hth individual as follows:

$$y_h = \alpha j_T + Z_h\beta + u_h j_T + e_h \tag{3.13}$$

where $y_h = (y_{h1}, y_{h2}, \ldots, y_{hT})$; Z_h is a TxK matrix; $j_T = (1\ 1\ \ldots\ 1)'$ is a T vector of ones and $e_h = (e_{h1}, e_{h2}, \ldots, e_{hT})$.

The term $(u_h j_T + e_h)$ can be regarded as a composite disturbance vector that has mean zero and covariance matrix:

$$V = \begin{bmatrix} \sigma_u^2 + \sigma_e^2 & \sigma_u^2 & \cdots & \sigma_u^2 \\ \sigma_u^2 & \sigma_u^2 + \sigma_e^2 & \cdots & \sigma_u^2 \\ \cdot & \cdot & \cdot & \cdot \\ \sigma_u^2 & \sigma_u^2 & \cdots & \sigma_u^2 + \sigma_e^2 \end{bmatrix} \tag{3.14}$$

The structure of this covariance matrix is such that, for a given individual, the correlation between any two disturbances in different time periods is the same. Thus, in contrast to a first order autoregressive model, the correlation is constant and does not decline as the disturbances become farther apart in time. Another feature of this matrix is that V does not depend on h.

An estimator of β can be obtained by applying GLS to equation (3.13). The same estimator can be obtained by applying OLS to the equation:

$$(y_{ht} - \tau \overline{y}_{h.}) = (1 - \tau)\,\alpha + \sum_{k=1}^{K} \beta_k\,(z_{kht} - \tau \overline{z}_{kh.}) + e_{ht} \qquad (3.15)$$

where $\tau = 1 - \sigma_e \,/\, (T\sigma_u^2 + \sigma_e^2)^{1/2}$.

To estimate σ_e^2 we can use the residuals from the fixed effects model, $\hat{e}$. An unbiased estimator for σ_e^2 is given by:

$$\hat{\sigma}_e^2 = \frac{\hat{e}'\,\hat{e}}{N - H - K} \qquad (3.16)$$

An estimator of σ_u^2 can be achieved by using the residuals from a regression on the individual means. If we average equation (3.13) over time we obtain:

$$\overline{y}_{h.} = \alpha + \sum_{k=1}^{K} \beta_k\,\overline{z}_{kh.} + u_h + \overline{e}_{h.} \quad , \quad h = 1,2,\ldots,H \qquad (3.17)$$

and the variance of the disturbance term in this equation is:

$$\mathrm{var}\,(u_h + \overline{e}_{h.}) = \sigma_u^2 + \sigma_e^2/T \qquad (3.18)$$

Thus by performing OLS on equation (3.17) an unbiased estimator of $\sigma_u^2 + \sigma_e^2/T$ can be obtained. Next, using the estimator of σ_e^2 an estimator of σ_u^2 can be calculated.

If the panel is incomplete, the covariance matrix is no longer the same for all individuals. The structure remains the same but the matrix is of order $d_h \times d_h$, where d_h denote the number of times individual h has been observed. The τ, used in the transformation carried out in equation (3.15) become for individual h: $1 - \sigma_e/(d_h\sigma_u^2 + \sigma_e^2)^{1/2}$ (Baltagi, 1985). To estimate σ_e^2 the residuals from the fixed effects model can be used. A consistent estimate of σ_u^2 can be obtained using equation (3.17), the variance of the disturbance term gives an consistent estimate for $\sigma_u^2 + \sigma_e^2\, d$, where:

$$d = \frac{1}{H} \sum_{h=1}^{H} \frac{1}{d_h} \qquad \text{(Greene, 1990: 174)}$$

A number of issues need to be considered when making a choice between a fixed or a random individual effect. When the number of farms H is large and the number of time-series observations T is small, just as is the case in this study, the two estimators can differ significantly. In this case the fixed effects estimator is still consistent but the random effects estimator will be more efficient. However, an important assumption, to be made for the random effects estimator to be consistent, is the independence of the individual effects and the regressors. A test of the appropriateness of this assumption can be based on the difference between the fixed effects estimator $\hat{\beta}_F$ and the random effects estimator $\hat{\beta}_R$. Hausman (1978) shows that:

$$m = (\hat{\beta}_F - \hat{\beta}_R)'(M_1 - M_0)^{-1}(\hat{\beta}_F - \hat{\beta}_R) \tag{3.19}$$

has an asymptotic χ^2_K distribution, where M_1 is the covariance matrix for the fixed effects estimator $\hat{\beta}_F$ and M_0 is the covariance matrix for the random effects estimator $\hat{\beta}_R$. If the null hypothesis is true (there is no correlation between the individual effects and the regressors) then asymptotically $\hat{\beta}_F$ and $\hat{\beta}_R$ differ only through sampling error. However if the individual effects and the regressors are correlated, $\hat{\beta}_F$ and $\hat{\beta}_R$ could widely differ, and it is hoped that this will be reflected in the test. Rejection of the null hypothesis suggests that the random effects model is not appropriate and that we are likely to be better off using the fixed effects estimator.

The model which we have to estimate consists of two equations. The two equations are connected because of the cross equation symmetry restriction, parameter α_2 appears in both equations. Because of this restriction and the possibility that the error terms of the demand function and the supply function may be correlated SUR (Judge et al. 1988:450) is an appropriate technique. However, for the random effects model with an incomplete panel there is no SUR estimation technique available in literature, therefore we estimate both models by OLS for the comparison. For calculating elasticities the fixed effects model is estimated by the SUR estimation technique (see Appendix B).

3.4 Data

Data used comes from a sample of Dutch farms where accounts of their farming activities are kept for the Agricultural Economics Research Institute. Annual data from dairy farms over the period 1970-1982 were used for estimation of the model. As the farms usually remain in the panel for about five years, the data set forms an incomplete panel. In total there were 2196 observations and 568 different farms in the sample.

Output and input prices are defined as Törnqvist price indices of components in the output and input types, see Appendix A and Higgens (1986). Higgens had only a cross-section of farms and therefore had to use the differences in prices between farms. By using a different price index per farm, however, the differences in prices between farms also result from differences in the quality of inputs and outputs (Quiggin and Bui-Lan, 1984: 45) and from differences in the composition of components. Therefore, this price index becomes an endogenous variable and would contradict the assumptions made in formulating the theoretical model. The price index used in this study is the average of the Törnqvist price index over the farms for one year. There are two disadvantages to this approach:

- differences in prices which are exogenous to the farmers (e.g. regional differences in prices) are treated in the same way as quality differences;
- the prices only differ over the years. The sample spanned the period 1970 - 1982, so we have thirteen observations of the normalized price. This restricts the possibility to distinguish many outputs and many variable inputs. For example, when two variable inputs are included then the output supply function, equation (3.6), would include three price variables and a trend term. Because of the high correlations between these variables together with the already mentioned measurement problems of the prices would result in unreliable estimates of the coefficients.

Three inputs were included in the profit function: labour, capital (with components livestock, buildings, machinery), and land. The output of the dairy farms contain as components milk and meat, the variable input contains as components three different kinds of feed, fertilizer, seed, pesticides, fuel, and contract work. Implicit quantity indices for the output, the variable input and capital were obtained as the ratios of the value to the Törnqvist price index. The quality differences are, therefore, reflected in quantity differences between farms. The normalized price used is the ratio of the Törnqvist price index of the variable input and the Törnqvist price index of the output. Technical change is, as usual, captured in a trend term. For a complete description of the data, see Section 1.3 and Appendix A.

Both the demand for the variable input and the supply of the output of the dairy sector are strongly influenced by the weather. Production volume can change over time without there being changes in inputs. Weather indices are added, therefore, to the demand function for the variable input and to the output supply function. A meteorological model has been used to calculate the weather indices. The climatic factors on which the index depends are rainfall, average temperature and hours of sunshine (Oskam and Reinhard, 1992).

3.5 Results

The demand function for the variable input and the supply function of the output with fixed effects were estimated according to equation (3.9). The random effects estimates were calculated using equation (3.15) taking into account that in this study only an incomplete panel is available. In this transformation the estimate of σ_e and the estimate of σ_u were used. The estimate of σ_e follows from residuals of the fixed effects model. The estimate of σ_u was obtained from using a regression of the individuals means as described in Section 3.4, whereby d is 0.3. The variables in the demand function for the variable input and the output supply function were transformed in a different way, using the different estimates given of σ_e and σ_u in Table 3.1. The parameters of the two models estimated are presented in Table 3.1.

For both models all parameters are significant at the 5% level except for the weather index in the supply function. Note that the standard errors of the coefficients of the fixed effects model are higher than the standard errors of the coefficients of the random effects model.

Table 3.1 Parameter estimates of the two models; standard errors are in parentheses

Variable	Fixed effects	Random effects	Difference
Price	44036.05	34946.62	9089.43
	(5272.25)	(4782.23)	(2218.82)
Input demand			
Capital	0.09	0.12	-0.02
	(0.01)	(0.01)	(0.00)
Land	8.68	9.57	-0.89
	(1.57)	(1.11)	(1.11)
Labour	2.71	4.35	-1.64
	(0.77)	(0.64)	(0.44)
Technical change	2261.08	2369.11	-108.03
	(249.54)	(215.87)	(125.19)
Weather	-60118.00	-17968.00	-42150.00
	(7434.97)	(5730.52)	(4737.06)
σ_e	13342.00		
σ_u	26336.00		
Output supply			
Capital	0.19	0.23	-0.04
	(0.01)	(0.01)	(0.00)
Land	37.83	39.12	-1.29
	(2.35)	(1.67)	(1.65)
Labour	7.94	7.13	0.81
	(1.15)	(0.96)	(0.65)
Technical change	4638.63	3735.04	903.58
	(372.72)	(321.68)	(188.28)
Weather	20440.50	-12180.00	32620.50
	(11092.79)	(8057.05)	(7624.56)
σ_e	19925.00		
σ_u	39886.00		
R^2			
- demand function	0.96	0.95	
- supply function	0.97	0.97	

A main aspect in this study is that individuals may have different intercepts. If they would all be the same and the other assumptions of the model continue to hold, then there is no need to account for the time-series cross-sectional nature of the data, and, for estimation purposes, the data can be treated as one random sample of N observations. The F-test, described in Section 3.3, was used to test the assumption of equal intercepts. The null hypothesis is rejected for both equations and we conclude that the intercepts of the farms' demand and output functions are not all the same.[3]

The consistency of the random effects estimator was tested. The specification test consists of seeing how large the difference in estimates is, $\hat{\beta}_F - \hat{\beta}_R$, in relation to its variance, $M_1 - M_0$.[4] Where M_1 is the covariance matrix for the fixed effects estimator $\hat{\beta}_F$ and M_0 is the covariance matrix for the random effects estimator $\hat{\beta}_R$. In comparing the estimates in column 1 and column 2 of Table 3.1 it is apparent that there are no differences in sign in the two sets of estimates with exception of the parameter of the weather index in the supply function. The estimates in column 1 and column 2 of Table 3.1 differ substantially in size relative to their standard errors (see column 3).
To test misspecification m is calculated, using equation (3.19),

$$m = (\hat{\beta}_F - \hat{\beta}_R)'(M_1 - M_0)^{-1} (\hat{\beta}_F - \hat{\beta}_R) = 683.96$$

Since m is distributed asymptotically as χ^2_{11} which has a critical value of 31.26 at the 0.1 per cent level, very strong evidence of misspecification in the random effects model is present. The fixed effects model, therefore, is used to calculate elasticities.

Before calculating these elasticities it is important to test the basic assumption underlying the methodology used in this study: i.e. that

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[3] For the demand function for the variable input we found a F statistic of 16.89 and for the supply function of the output we found a F statistic of 16.99. For (567, 1622) degrees of freedom and a 1 per cent significance level the critical F value is about 1.1.

[4] The variance of the asymptotic distribution of $\sqrt{H}\,(\hat{\beta}_F - \hat{\beta}_R)$ must be determined. since $\hat{\beta}_F$ and $\hat{\beta}_R$ use the same data, they will be correlated which could lead to messy calculation for the variance of $\sqrt{H}\,(\hat{\beta}_F - \hat{\beta}_R)$. Luckily, the variance of $(\hat{\beta}_F - \hat{\beta}_R)$ is equal to $(M_1 - M_0)$ under the null hypothesis of no misspecification (Hausman, 1978: 1253).

farmers are profit-maximizers. According to this assumption the normalized profit function should be convex in the price p. As can be concluded from Table 3.1, this assumption holds for the fixed effects model, because the price coefficient is greater than zero. The symmetry restriction was tested by an F test. The demand equation for the variable input and the supply equation of the output were estimated without the cross equation restriction on the parameter α_2. For the demand function for the variable input we found a F statistic of 5.65 and for the supply function of the output we found a F statistic of 5.05. For (1,1622) degrees of freedom and a 1 per cent significance level, the critical F value is about 6.7.[5] Therefore, the null hypothesis is not rejected and the symmetry restriction is maintained. Thus, the assumptions in the model according to neoclassical theory are not rejected. This is in contrast with previous studies (see Lopez (1984a), Higgins (1986) and Burrell (1989)).

The elasticities of prices and inputs were calculated for the demand function for the variable input and the supply function of the output. The equations were estimated with and without fixed effects, using the SUR estimation technique. The standard errors were calculated on the basis of the standard errors of the coefficients.

The differences between the elasticities of the model without dummies and the model with dummies are remarkable. Only for the labour input the differences are small. The differences between the two models are caused by the omitted variable (quality of land and labour) in the model without dummy. For example, the elasticity of capital is higher in the model with dummies than in the model without dummies. A farm with a high quality level of labour and land will have more capital per unit of labour and land. Differing the intercept over the farms results, therefore, in lower elasticities of capital, see Mundlak (1961). As has already been pointed out, the fixed effects model should be preferred.

It can be concluded from Table 3.2 that the price elasticity of the demand for the variable input is small, −0.25. The elasticity of the output with respect to the price of the variable input is even smaller,

[5] With a large sample size it is more appropriate to choose a small significance level (Leamer, 1978, Chapter 4).

Table 3.2 Elasticities at the sample mean (standard errors in parentheses)

	Price input	Capital	Land	Labour	Technical change
Demand function without dummy	-0.03 (0.14)	0.89 (0.03)	-0.03 (0.03)	0.14 (0.04)	0.014 (0.002)
Demand function with dummy	-0.25 (0.07)	0.45 (0.01)	0.23 (0.04)	0.14 (0.05)	0.025 (0.003)
Supply function without dummy	-0.01 (0.06)	0.69 (0.01)	0.26 (0.02)	0.13 (0.02)	0.009 (0.002)
Supply function with dummy	-0.10 (0.03)	0.37 (0.01)	0.43 (0.03)	0.17 (0.03)	0.023 (0.001)

−0.10.[6] The elasticities with respect to the output price are, as a result of the homogeneity restriction, the opposite of these elasticities.

Comparing these results with results from other studies indicate that the estimates of the price elasticities presented in Table 3.2 are low, with the exception of the study of Elhorst (1990:104). Starting from a quadratic profit funtion, using data of Dutch dairy farms over the period 1980-1983 and a random effects estimator, Elhorst obtained an own-price elasticity of milk of 0.12. Higgins obtained a compensated own-price elasticity for milk of 0.17 and a feed compensated own-price elasticity of -0.43 for Irish farms. Oskam and Osinga (1982) obtained an own-price elasticity for milk at a term of one year of 0.29, using aggregate data of the Dutch dairy sector.

The elasticities of the fixed inputs in the output supply equation can be divided into two effects:

[6] The low price elasticity of the output could be due to the prices which are used in the analysis: prices in the same year. Correlation between the disturbance of the output supply equation and the price variable could arise. For example: let assume that for a particular reason supply is low. This would result in an increase in the milk price. Such a relative high milk price comes together with a relative low milk production and a negative disturbance term. However, part of this problem has been eliminated by including a weather variable in the supply equation. The price elasticity of the output, when the price of the output is delayed by one year, is equal to 0.17. The price elasticity of the variable input is -0.39.

- a direct effect, by way of the production function, equation (3.2);
- an indirect effect by way of the demand function for the variable input, equation (3.4).

Formally, using equation (3.2):

$$\left[\frac{\partial q}{\partial x}\right]_{total} = \left[\frac{\partial q}{\partial x}\right]_{pe} + \left[\frac{\partial q}{\partial v}\right]_{pe} * \left[\frac{\partial v}{\partial x}\right]_{df} \qquad (3.20)$$

Therefore,

$$\left[\frac{\partial q}{\partial x}\,\frac{x}{q}\right]_{total} = \left[\frac{\partial q}{\partial x}\,\frac{x}{q}\right]_{pe} + \left[\frac{\partial q}{\partial v}\,\frac{v}{q}\right]_{pe} * \left[\frac{\partial v}{\partial x}\,\frac{x}{v}\right]_{df} \qquad (3.21)$$

where on the left hand side of the equal sign stands the total effect of the change in the fixed input x on the output q. The first term on the right hand side is the production elasticity (pe) of the output with respect to the fixed input. The second term is the production elasticity of the output with respect to the variable input v and the third term is the elasticity of the fixed input in the demand function (df) for the variable input. The price elasticity of the output is equal to the production elasticity of the variable input times the price elasticity of the variable input.

The total effect of the price and the total effect of the fixed inputs in Table 3.3 do not significantly differ from the results in Table 3.2.[7] The elasticity of the output with respect to capital is mainly caused by the indirect effect and is not very high, 0.36. We expect, therefore, that the price elasticity of the output is in the intermediate-run and the long-run also not very large. In Chapter 5 this remark will be investigated. The influence of land on the demand for the variable input and the supply of the output is large. This is caused by the scarcity of land in the Dutch agricultural sector, the production elasticity is 0.30, and the positive relation between the demand for the variable input and land, the elasticity is 0.23. Remarkable is the large influence of technical

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[7] The total effect of the price in Table 3.3 is 0.15, the price elasticity in Table 3.2 is 0.10. The difference is 0.05, with a standard deviation of 0.05. The difference is, therefore, not significant.

change on the input and the output (see Table 3.2). The influence of technical change on the input and output is defined as the derivative to the trend term divided by the input and the output, respectively. The influence of technical change is a sort of rest term, the change in the input and output that can not be explained by a change in the amount of the fixed inputs and the prices. This rest term is 0.025 for the demand function for the variable input, which means a growth of the variable input by 2.5% per year. This increased demand for the variable input is caused by new breeding techniques with respect to cows, resulting in a higher feed intake per cow and a transition from roughage to concentrates. The influence of technical change on the supply of the output is mainly caused by the indirect effect (see Table 3.3).

Table 3.3 Dividing the elasticities of the supply function into a direct effect and an indirect effect at the sample mean, standard errors in parentheses[1]

	Direct effect[2]	Indirect effect[3]	Total effect
Price		0.15	0.15
		(0.04)	(0.04)
Capital	0.09	0.27	0.36
	(0.02)	(0.01)	(0.02)
Land	0.30	0.14	0.44
	(0.03)	(0.02)	(0.04)
Labour	0.09	0.08	0.17
	(0.02)	(0.03)	(0.04)
Technical change	0.006	0.015	0.021
	(0.002)	(0.002)	(0.003)

[1] The standard errors in column two and three are calculated assuming that the elasticities are independent.

[2] Production elasticities obtained from Table 2.5, p.26.

[3] Elasticity of the variable input of the production function 0.6 (0.03) (see p.26) multiplied by the elasticities of the demand function for the variable input, see Table 3.2.

3.6 Conclusions

Starting from neoclassical theory using the dual approach, a system of factor demand and output supply was estimated using an incomplete panel. The main conclusions obtained from the study are:

(a) The model postulated seems to provide an appropriate description of the input and output decisions of dairy farmers in the Netherlands, because the assumptions underlying it are not rejected by the data and the elasticity estimates are reasonable.

(b) Because panel data are available one may allow for the possibility that the intercept in the demand function for the variable input and the intercept in the output supply function vary over the farms. It turns out that these intercepts are not the same for all farms. These intercepts reflect mainly managerial differences and differences in the quality of land between farms.

(c) The farm specific intercepts in the two equations can be assumed to be random or fixed. The random effects estimator is more efficient than the fixed effects estimator. However, an important assumption which has to be made if the random effects estimator is to be consistent is the independence of the individual effects and the regressors. Using a Hausman test this assumption is rejected. Therefore, the fixed effects estimator is preferred.

(d) The own-price elasticity of the output is 0.10. The price elasticity of the demand for the variable input is -0.25. These estimates are smaller than calculated elasticities in other studies. The possibilities of the traditional agricultural policies and of environmental policies to influence the level of supply with levies or subsidies are, therefore, small in the short-run.

(e) The elasticities of the output to the fixed inputs are equal to the sum of the production elasticity of the fixed inputs and the elasticities of the fixed inputs in the demand function of the variable input times the production elasticity of the variable input. The elasticity of land in the output supply function is 0.43, this effect is mainly caused by the production elasticity. On the contrary stands the influence of capital on the output, elasticity is 0.37. This is mainly caused by the large influence of capital on the demand for the variable input. The influence of technical change in the production function is only 0.6% per year, the total effect of technical change in the output supply function is 2.1%.

CHAPTER 4

LABOUR SUPPLY FUNCTION

The supply elasticity of family labour on dairy farms is estimated using a utility function with consumption goods and leisure as variables, and a non-linear budget constraint linking income through a quadratic profit function to labour supply. Using a local linear approximation to this constraint and distinguishing one other variable input, the endogenous wage elasticity of labour supply is derived. It turns out to be small.

4.1 Introduction

In Chapters 2 and 3 it is assumed that the farm family's objective is to maximize short-run profit. The focus was on the output supply and the demand for the variable input. Labour was assumed to be fixed. In this chapter the supply of family labour is analysed. Introducing labour as a variable input in the model allows the possibility of a backward sloping supply curve to be analysed. In most European countries the supply of farm products is increasing whereas their prices are falling. Does this mean that the price elasticity of supply is negative? Will the farm family work more hours and increase their production in order to lessen the decline in their income level if prices go down? (Boussard, 1985: 31-33). In this chapter this assumption will be formalized: a labour supply function of farm households will be developed and estimated, starting from a model of the agricultural household.

Economists measuring behavioural responses of farm households have typically used recursive models (for an overview of this empirical literature, see Singh et al., 1986a). That is, they have assumed that production conditions (farm technology, input, and output prices) affect consumption and labour supply decisions exclusively via income levels, and that production decisions are entirely independent of decisions about consumption and labour supply. Thus, these studies consider a one-way effect (from the production sector to the consumption sector) only, and, moreover, this relation is restricted to the income effect. Changes in the production sector have no implications for the shadow prices of labour or consumption. This assumption has allowed researchers to estimate the consumption and production sectors of the model independently or, more frequently, recursively.

Lopez (1984b) has developed a micro-economic model that integrates the production and labour decisions of a farm household into a unified theoretical framework. The theory starts from a utility function, with consumption goods and leisure as variables. These two variables are linked through the definition of income and a profit function. The derived budget constraint is non-linear. It has to be linearized, because otherwise the body of established results of traditional demand theory cannot be exploited. To obtain a linear budget constraint, Lopez assumed that there are no fixed factors of production and the production technology exhibits constant returns to scale.

In this chapter the approach of Lopez is pursued, but a new approximation of the budget constraint is analysed. Another difference with previous studies in agriculture, is the use of a cost function, based on duality theory.[1] Annual data from dairy farms in the Netherlands over the period 1970-1982 were used for estimation of the model. The estimated profit function is quadratic. For the cost function a flexible specification was used that underlies the Almost Ideal Demand System. The availability of panel data made it possible to estimate the equations with intercepts that vary over farms. The effects of a decline in the output price on labour supply, output supply and the demand for the variable input were calculated.

The remainder of this chapter is organized as follows. In Section 4.2 the theory underlying this study is presented. The demand function for leisure is derived and the way the budget constraint is linearized is pointed out. In Section 4.3 the model is specified, using flexible functional forms. The data used and the way the equations were estimated is described in Section 4.4. The estimated parameters, elasticities and tests carried out are presented in Section 4.5. Conclusions are presented in Section 4.6.

4.2 Theoretical model

In general, any analysis of the labour supply of agricultural households has to account for the interdependence of farm production and consumption

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[1] Kooreman and Kapteyn (1985) have developed this approach for households in general.

of leisure. Agricultural households combine the household and the firm: two fundamental units of microeconomic analysis. It is assumed that the farm family, as an entity, maximizes a well-behaved utility function, which depends on the consumption of goods (y) and leisure (f):

$$U = u(y,f) \tag{4.1}$$

Leisure is the number of leisure hours associated with on-farm work. Off-farm work is not taken into account, because in the data set used there was little off-farm work, and the amount of off-farm work has not changed very much over the sample period despite the large change in the unemployment rate. Another assumption is that no distinction is made between leisure of the different members of the farm family. Only one category of family labour is taken into account, however the total sum of hours worked on the farm is corrected for differences in the quality of labour between the family members.

Utility is maximized subject to a production constraint or production technology that depicts the relationship between inputs and farm output:

$$q = q(v,l,k,g,t) \tag{4.2}$$

where q is a concave production function; v is the variable input (feed, fertilizer, etc.); l is family labour; k is capital (livestock, buildings and machinery); g is land; t is technology.

The household also faces a time constraint. It cannot allocate more time to leisure and farm labour than the total time available to the household:

$$f + l = aT \tag{4.3}$$

where a is the number of potential family workers; T is total number of hours that a household member has available for all activities; l is the number of hours of work supplied by household members.

In this chapter, only short-run decisions are considered. The relevant income definition is therefore the sum of the difference between revenues and the cost of variable inputs and net non-labour income:

$$p_y y = p_q q - p_v v + n \tag{4.4}$$

where p_y is the price of the consumption goods; p_q is the price of the output; p_v is the price of the variable input; n is net non-labour income (e.g. the difference between the revenue from interest and interest paid).

Assuming utility maximizing behaviour implies that the short-run profit is maximized.[2] According to duality theory this short-run profit maximizing behaviour can be presented by a profit function, see Chapter 2. This profit function is normalized by the price of the output, to ensure that the profit function is linearly homogenous in prices. Restrictions of the normalized short-run profit function that will be tested are convexity in the normalized price and concavity in labour. By Hotelling's Lemma, if we differentiate the short-run profit function with respect to the normalized price, we obtain the demand function for the variable input.

Using the normalized profit function the constraints on household behaviour can be amalgamated into a single budget constraint:

$$p_y y = p_q \, \pi \, (p, aT - f, k, g, t) + n \tag{4.5}$$

where p is the ratio of the price of the variable input to the price of the output; π is the profit function normalized by the output price.

As the budget constraint is non-linear in f, there is no access to the body of established results of traditional demand theory. Epstein (1981a) developed a generalized duality theory that is not restricted to a linear budget constraint. However, in that general model, Roy's identity or Shephard's Lemma do not yield the demand functions for leisure and income. Therefore, assumptions are made to linearize the budget constraint. In the literature two assumptions are proposed:

1. Family labour is perfectly mobile, all labour is valued at the market wage. The consequence of this assumption is that the only linkage between the consumption and production sides of the model is the effect of profits from the farm operation on the household income (Singh et al., 1986b);
2. There are no fixed factors of production and the production technology exhibits constant returns to scale. Therefore, the hourly earnings on the

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[2] This can easily be seen by solving the Lagrange equation belonging to the equations (4.1) - (4.4) for the variable input.

farm are independent of the labour volume, line 1 in Figure 4.1 (Lopez, 1984b).

The first assumption is unlikely for the Netherlands. As Elhorst (1990:44-45) argues farm households have different utility connotations for farm and off-farm work and the hourly earnings differ for these two types of labour. Lopez (1984b) rejected the hypothesis of independence between utility maximizing and profit maximizing decisions. The second set of assumptions, made by Lopez, is also unlikely. The assumption of constant returns to scale is rejected in Chapter 2, see Table 2.4, p.25.

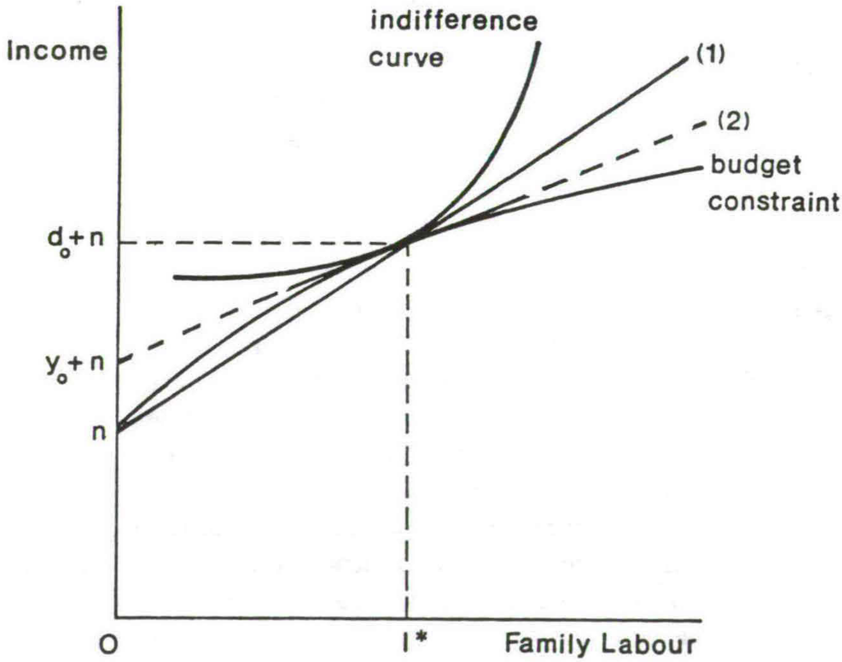

Figure 4.1 Two approximations of the non-linear budget constraint

Therefore, in this chapter another approximation of the budget constraint is introduced. The non-linear budget constraint is approximated by a linear constraint that passes through the optimum point, line 2 in Figure 4.1. With the profit function the marginal income of labour (the slope of line 2) can be calculated at the actual level of labour on the farm. It is assumed that the actual labour supply of the farm family is in accordance with the solution of the utility maximizing problem: the slope of the budget constraint equals the slope of the indifference curve (I^* in Figure 4.1). This approximation will now be formulated in algebraic terms.

A first order approximation of the non-linear budget constraint, equation (4.5), at f^*, with $df = f^* - f = l - l^*$ is:

$$\begin{aligned} p_y y &= p_q\, \pi\, (p, aT - f^*, k, g, t) + n \\ &\quad + df\, p_q \{ \partial\pi\, (p, aT - f^*, k, g, t)/\partial f \} \\ &= d_0 + n + df \cdot w \\ &= d_0 + n + (l - l^*) \cdot w \\ &= y_0 + n + w \cdot l \end{aligned} \tag{4.6}$$

where w is the marginal wage rate of labour on the farm. The marginal wage rate of labour is thus the derivative of $p_y y$ at f^*, and is, therefore, equal to the marginal profit of an extra hour of work at l^*. y_o is the income at l^* minus $w \cdot l^*$ (see Figure 4.1). To obtain a standard utility maximization problem this budget constraint has to be transformed. Using (4.3) and (4.6) the full income constraint is:

$$p_y y + wf = aTw + n + y_0 \equiv Y \tag{4.7}$$

where Y is full income.

The decision process of the farm household is approximated by maximizing the utility function (4.1) subject to (4.7), which results in a demand for leisure function and a demand function for consumption goods. The mathematical form of these functions depends on the specification of the utility function. Since economic theory is unspecific about the functional form it is advisable to choose a flexible specification so that the data help to specify the functional form of the demand equations. However, starting with a flexible functional form for the utility function it is extremely difficult to derive the so-called Marshallian demand equations. Therefore, duality theory has been used. According to duality theory, utility maximizing behaviour subject to a linear budget constraint can equivalently be represented by the cost function $c(u,p_y,w)$. This function represents the minimum amount of money required to reach utility level u, given prices p_y and w. If the cost function satisfies certain regularity conditions, it is dual to the utility function. A testable condition of regularity is concavity of the cost function in prices. If the cost function is differentiated with respect to prices, the demand functions corresponding to utility maximization are obtained directly:

$$f = h(u,p_y,w) = \frac{\partial c(u,p_y,w)}{\partial w} \tag{4.8}$$

Substituting the indirect utility function for u gives the Marshallian demand equations (Deaton and Muellbauer, 1980:37-42).

4.3 Specification of the model

The central equation in this chapter is the demand function for leisure, equation (4.8). The crucial variable in the demand function for leisure is the marginal wage rate of labour on the farm. This variable can be calculated using the budget constraint. The budget constaint is reflected by the normalized short-run profit function. Therefore, three equations will be estimated: the normalized short-run profit function; the related demand function for variable inputs; and the demand function for leisure. In this section these equations will be specified and expressions for the marginal wage rate, concavity constraints and elasticities will be derived. The intercepts of the profit function, the demand function for the variable inputs, and the demand function for leisure vary over the farms. This intercept reflects e.g. managerial differences and differences in the quality of land across farms.

Assuming the quadratic specification, the normalized short-run profit function for farm h is written as:

$$\begin{aligned}\pi_h &= \alpha_{oh} + \alpha_1 p + \sum_{i=2}^{5} \alpha_i x_{ih} + \tfrac{1}{2}\, \alpha_{11} p^2 \\ &\quad + \sum_{i=2}^{5} \alpha_{1i} p x_{ih} + \tfrac{1}{2} \sum_{i=2}^{5} \sum_{j=2}^{5} \alpha_{ij} x_{ih} x_{jh}\end{aligned} \tag{4.9}$$

where $\alpha_{ij} = \alpha_{ji}$; x_i are the inputs (with i = 2 or l (labour), 3 or k (capital), 4 or g (land), 5 or t (technology)).

By Hotelling's Lemma, if we differentiate the normalized short-run profit function with respect to the normalized price, we obtain the demand function for the variable input (v):

$$v_h = -(\alpha_{1h} + \alpha_{11}p + \alpha_{12}l_h + \alpha_{13}k_h + \alpha_{14}g_h + \alpha_{15}t) \tag{4.10}$$

An expression for the marginal income of labour per firm is calculated using the normalized profit function. The marginal wage rate of labour is the derivative of income to labour:

$$\begin{aligned} w_h &= \frac{\partial p_y y_h}{\partial l_h} \\ &= p_q \frac{\partial \pi_h}{\partial l_h} = p_q(\alpha_2 + \alpha_{12}p + \alpha_{22}l_h + \alpha_{23}k_h + \alpha_{24}g_h + \alpha_{25}t) \end{aligned} \tag{4.11}$$

The marginal wage rate of labour is a function of prices and fixed inputs but also of the input of labour.

Now we come to the central equation in this chapter: the demand function for leisure. This demand function is obtained by differentiating the cost function to the price of leisure. The specification used was the cost function underlying the Almost Ideal Demand System, developed by Deaton and Muellbauer (1980:75)[3]:

$$\begin{aligned} \log c(u,w,p_y) &= \beta_{0h} + \beta_1 \log w + \tfrac{1}{2}\beta_2 (\log w)^2 \\ &\quad + \beta_3 u w^{\beta_4} p_y^{\beta_5} + \beta_6 \log w \log p_y \\ &\quad + \beta_7 \log p_y + \tfrac{1}{2}\beta_8 (\log p_y)^2 \end{aligned} \tag{4.12}$$

Acccording to the neoclassical theory the cost function should be linearly homogeneous in prices, therefore:

[3] To improve the readability of the formulae the index h has been removed from the variables c, u and w.

$$\log \frac{c(u, \frac{w}{p_y})}{p_y} = \beta_{0h} + \beta_1 \log \frac{w}{p_y} + \tfrac{1}{2}\beta_2 (\log \frac{w}{p_y})^2 + \beta_3 u (\frac{w}{p_y})^{\beta_4} \tag{4.13}$$

This is the real cost function, representing the minimum amount of real money required to reach utility level u, given the real marginal wage rate of labour. For notational convenience w and c(u,w) will from now on represent real marginal wage rate and real money, respectively.

Differentiating the cost function with respect to the price leads to the compensated (Hicksian) demand function at utility level u. By next solving (4.13) for u and substituting the solution for u in the compensated demand function, the uncompensated demand function is obtained:

$$\begin{aligned} sh = \frac{w \cdot f}{Y} = \beta_1 + \beta_2 \log w + \beta_4 \log Y - \\ \beta_4 [\beta_{0h} + \beta_1 \log w + \tfrac{1}{2} \beta_2 (\log w)^2] \end{aligned} \tag{4.14}$$

where sh is the share of the value of leisure in the household's full income. The basic assumption underlying the methodolgy used in this study is utility maximizing behaviour. When the cost function is concave in the wage rate of labour, then the costs are minimized or, equivalently, utility is maximized. (Deaton and Muellbauer, 1980: 39-45). The cost function is concave if and only if:

$$\beta_2 + \beta_4^2 [\log Y - \beta_{0h} - \beta_1 \log w - \tfrac{1}{2}\beta_2 (\log w)^2] - sh + sh^2 \leq 0 \tag{4.15}$$

This condition is equivalent to the negativity condition, which refers to the derivative of the Hicksian demand function with respect to the price.

The price elasticity of leisure is derived from equation (4.14):

$$\frac{\partial f}{\partial w} \cdot \frac{w}{f} = \frac{sh\,aT}{f} - 1 + \frac{\beta_2}{sh} + \beta_4 [\frac{aT}{f} - \frac{\beta_1}{sh} - \frac{\beta_2}{sh} \log w] \tag{4.16}$$

The price elasticity of labour can be calculated from (4.16) with (4.3).

4.4 Data and estimation

The data used come from a sample of Dutch farms which kept accounts of their farming activities for the Agricultural Economics Research Institute. Annual data from dairy farms over the period 1970-1982 were used for estimation of the model. As the farms usually remain in the panel for about five years, the data set forms an incomplete panel. In total there are 2196 observations and 568 different farms in the sample.

Three inputs were included in the profit function: labour in hours (family and hired labour[4]), capital (livestock, machinery and buildings) and land. The amount of family labour is the calculated remuneration of family labour divided by the hourly wage costs of a farm worker. The hours worked by children are calculated by a smaller remuneration than the hours worked by the farmer, therefore the total sum of hours worked by the farm family is in some degree corrected for differences in quality on the farm. Implicit quantity indices for the variable input and capital were obtained as the ratios of the value to the Törnqvist price index. The normalized price is the ratio of the Törnqvist price indices of the variable input and the output. Normalized profit is defined as the value of output minus the value of the variable divided by the normalized price. The Törnqvist price index used is the annual average of the price indices of the different farms. For a complete description of the data, see Section 1.3 and Appendix A.

Because profits of the dairy sector are strongly influenced by the weather, a weather index with parameter α_w was added to the profit function. A meteorological model was used to calculate the weather indices (Oskam and Reinhard, 1992).

The marginal wage rate of labour, full income and share value of leisure were based on own calculations. The share value of leisure (see equation (4.14)) can be greater than one because full income depends on non-labour income too, which can be negative because of interest and depreciation costs. Note that the variability in the marginal wage rate of labour across farms is not very large.

The demand function for leisure depends on the marginal wage rate of labour on the farm and full income (both in real prices). To obtain real values the general Dutch price index was used. To calculate full income

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[4] Because the amount of hired labour in the sample is very small (about 5% of the total labour volume), hired labour has been treated as exogenous.

it is assumed that the total number of hours that a household member has available for all activities is 5840 hours per year, that is 16 hours per day. The number of potential family workers and non-labour income are given in the data set.

Marginal wage rate of labour was calculated per farm after the normalized short-run profit function and the related demand function for the variable input were estimated, equations (4.9) and (4.10), respectively.

Table 4.1 Short description of the data

	Mean	Standard deviation	Minimum value	Maximum value
Output (1000 guilders)*	203.5	128.7	13.8	1083.1
Variable input (1000 guilders)*	87.5	62.4	3.8	481.3
Family labour (hours)	4187.3	1252.2	702.9	10273.7
Capital (1000 guilders)*	403.2	265.7	56.4	2238.1
Land (hectares)	23.3	11.4	3.5	108.0
Number of potential workers	2.1	0.3	2.0	4.0
Marginal wage rate of labour (guilders per hour of labour)*	6.7	0.7	3.6	8.6
Full income (1000 guilders)*	129.1	44.7	38.8	536.6
Share value of leisure	0.47	0.16	0.09	1.09

* In 1980 prices.
Source: Agricultural Economics Research Institute and own calculations.

Additive error terms are added to the normalized short-run profit function and the related demand function for the variable input because:

- farmers are profit maximizers but they will not always succeed in choosing levels of output and inputs that will lead to a maximum level of profit;
- the functional form distinguished is an approximation of the true underlying short-run profit function.

A fixed effects estimator was used to take the variable intercept into account, see also Appendix B.[5]

Assuming that the stochastic variable labour is uncorrelated with the error term, SUR (Judge et al., 1985:467) is an appropriate technique because of the cross-equation symmetry restrictions and the possibility that the error terms of the profit equation and the related demand equation for the variable input may be correlated. The assumption that labour and the error term are independent was tested using a Hausman test. To implement the Hausman test two estimators have to be constructed. One is the already mentioned SUR estimator. This estimator is consistent and efficient under the null hypothesis that labour and the error term are independent. When labour and the error term are not indepedent, an instrumental variable estimator like 3SLS is a consistent estimator. The endogenous variables are: π, v, $l{\cdot}p$, $l{\cdot}x_j$ (j = l,k,g,t). The instruments used are the exogenous variables in the model, the age of the farmer and farm size, all in levels and in terms of deviations from unit sample means. A Hausman test can easily be implemented using these estimators and the corresponding variance matrices (see Section 3.3 and Maddala (1989: 435-436).

An error term is also added to the share equation for leisure (equation (4.14)), to take account of (i) measurement errors in the dependent variable and the marginal wage rate of labour, (ii) difference between the Almost Ideal Demand System and the true underlying functional form and (iii) optimization errors. A fixed effects estimator was used to take the variable intercept into account.

The error term of the share equation will most likely be correlated with the marginal wage rate of labour. The equation was estimated with 2SLS, the endogenous variables are sh, log w, log Y and $(\log w)^2$, instruments used are the exogenous variables in the model (capital, land, prices and technology) in levels and in terms of deviations from unit sample means, age of the farmer, farm size, number of potential farm workers, non-labour income, and the presence of a successor.

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[5] In Chapter 3 it has been shown that the fixed effects estimator should be preferred to the random effects estimator.

4.5 Results

The parameters of the estimated profit function and the related demand function for the variable input are given in Table 4.2.[6] The SUR estimation method was used. The consistency of the SUR estimator was tested, using a Hausman test. The Hausman test statistic is distributed asymptotically as a χ^2 distribution with 21 degrees of freedom. The test statistic is equal to 33.1, which is not significant at the 1% level. Thus we can treat labour as exogenous and estimate the profit function and the related demand function by SUR.

Table 4.2 Parameter estimates of the normalized profit equation and the demand equation for the variable input*

Parameter	Coefficient	Standard error	Parameter	Coefficient	Standard error
a_p	- 57399.0	10065.1	a_{lk}	- 7.0	317.7
a_l	8512.9	3115.6	a_{lg}	104.9	890.5
a_k	14237.3	2029.8	a_{lt}	207.9	203.5
a_g	35860.9	5458.1	a_{kk}	- 648.6	264.6
a_t	5155.9	1165.6	a_{kg}	1762.2	539.6
a_{pp}	20971.0	6288.4	a_{kt}	272.1	161.1
a_{pl}	- 2733.5	777.2	a_{gg}	- 4497.1	1790.9
a_{pk}	- 10124.0	442.5	a_{gt}	498.8	355.1
a_{pg}	- 9082.7	1561.5	a_{tt}	- 465.1	106.9
a_{pt}	- 2100.3	251.6	a_w	81946.9	8103.8
a_{ll}	- 396.3	648.8			

* The subscripts p, l, k, g, t, w refer to normalized price, labour, capital, land, technology, and weather, respectively.

[6] In estimating the profit function and the related demand function for the variable input some inputs are transformed: labour is in 1000 hours, land in 10 hectares, and capital in 100 000 guilders of 1980.

The adjusted R^2 of the profit function is 0.99 and it is 0.98 for the demand equation for the variable input. The normalized profit function is convex in the normalized price ($\alpha_{pp} > 0$) and concave in labour ($\alpha_{ll} < 0$). The assumption of short-term profit maximization behaviour is, therefore, not rejected by the data.

Using these estimated functions the marginal wage rate of labour on the farm and full income were calculated using equations (4.11) and (4.7), respectively. The marginal wage rate of labour turns out to be 6.7 guilders of 1980 per hour of labour on average (see Table 4.1). This is about 40% of the labour costs per hour of farm workers.

Using the calculated marginal wage rate of labour the share equation for the demand for leisure was estimated. A Hausman test was used to test the null hypothesis that the error term of the share equation for leisure is independent of the variables on the right-hand side of this equation (marginal wage rate of labour and full income). The Hausman test statistic is distributed asymptotically as a χ^2 distribution with 3 degrees of freedom. The test statistic is equal to 58.6, which is significant at the 1% level. Thus the null hypothesis is rejected and an instrumental variable estimation procedure (2SLS) was used to estimate the share equation for leisure. The parameter estimates of the share equation for leisure are presented in Table 4.3. As can be concluded from Table 4.3 two of the three parameters are not significant at the 1% level. Therefore the results should be interpreted with caution. The adjusted R^2 of the share equation for leisure is equal to 0.92. When no fixed effects are taken into account the R^2 is equal to 0.68. For the profit function this difference in R^2 is not so large.

One aspect of the demand function for leisure is that individuals may have different intercepts. If they were all the same and the other assumptions of the model continued to hold, then there would be no need to account for the time-series cross-sectional nature of the data, and, for the

Table 4.3 Parameter estimates of the demand function for leisure; standard errors in parentheses

β_1	β_2	β_4	Number of observations	R^2
1.55	-0.14	-0.41	2196	0.92
(4.04)	(0.93)	(0.02)		

estimation, the data could be treated as one random sample of N observations. The F-test, described in Chapter 3 (p.35), was used to test the assumption of equal intercepts. The null hypothesis is rejected and we conclude that the intercepts of the farms' demand for leisure functions are not all the same.[7]

The neo-classical model of household utility maximization requires the cost function to be concave in the wage rate of labour. This condition is fulfilled at the sample mean. Also per observation point, it can be checked whether this condition is satisfied. It turns out that for 73% of the observations the cost function is concave, and thus behaves consistently with utility maximization within the developed model. Since any empirical model is bound to suffer from some degree of misspecification, and because there will always be random factors not captured by the model, utility maximization is maintained in the developed model and some further implications of the empirical results were explored.

In Table 4.4 the results are compared with studies of Lopez (1984b), Elhorst (1990) and Jacoby (1990). The similarity is remarkable. Lopez used a cross section from aggregate data from Canada. Elhorst used panel data from Dutch dairy farms over the period 1980-1986. Jacoby used a cross section from Peruvian households over 1985.

The on-farm wage elasticity is positive when evaluated at mean values. However, this elasticity is negative in 28% of the observations. But in almost all of the observations, labour supply is not very responsive to changes in labour income per hour. About two-thirds of the calculated elasticities are larger than -0.28 and smaller than 0.44.

Table 4.4 Utility maximization and labour supply elasticities

Study	Utility maximization: % observations	Labour supply elasticity, at the sample mean
Lopez (1984)	38	0.12
Elhorst (1990)	68	0.21
Jacoby (1990)	-	0.10
This chapter	73	0.19

[7] For the demand function for leisure we found a F statistic of 41.14. For (567,1625) degrees of freedom and a 1 per cent significance level the critical F value is about 1.1.

The effect of a decline in the output price can be analysed with the model developed in this chapter. The model consists of a quadratic profit function, a related demand function for the variable input and a share function for leisure. A change in the output price induces a shift in the budget constraint and therefore line (2) in Figure 4.1 changes. The wage rate of labour (the slope of line (2)) declines by 1.18% if the output price declines by 1%. Given the preferences of the family and the changed linear budget constraint, the supply of hours worked on the farm is adjusted. Using the labour supply elasticity (0.19) the change in the supply of hours worked is equal to -0.22%. Using the elasticities of the variable input and the output with respect to labour, which are approximately the same as those given in Table 3.2 (p.44), the ultimate changes in the variable input and the output are equal to -0.25 and -0.13 respectively.

As can be concluded from columns 1 and 2 of Table 4.5, endogenizing labour in a model of the farm family has little influence on how farmers react to changed prices.

Table 4.5 Effects of a 1% fall in the output price at the sample mean (in %)

	Labour volume constant	Labour volume variable
Wage rate of labour	-	- 1.18
Labour volume	0	- 0.22
Variable input	- 0.22	- 0.25
Output	- 0.09	- 0.13

4.6 Conclusions

In this chapter, a microeconomic model integrating the production and labour decisions in the short-run of a farm household into a unified theoretical framework was developed. The model postulated seems to provide an appropriate description of the short-run labour supply decisions made by dairy farmers in the Netherlands, because the assumptions underlying it are not rejected by the data and the elasticity estimates are reasonable.

The on-farm wage elasticity is 0.19 at the sample mean. The similarity with results of other studies is remarkable. A 1% fall in the output price causes a short-run fall of 0.1% in output, 0.2% in variable intput and 0.2% in labour. Endogenizing labour in a model of the farm family has little influence on how farmers react to changed prices. This is because the values of the elasticity of labour in the output supply equation and the price elasticity of labour are small.

CHAPTER 5

A DYNAMIC MODEL

A dynamic equation system of factor demand, based on the adjustment cost hypothesis, is estimated using an incomplete panel of Dutch dairy farms. The intercepts in the profit function, the demand function for the variable input and the demand function for capital, vary over the farms. An instrumental variable estimator is used, based on first differences of the variables.

The theoretical framework fits the data well. Investments are sensitive to price changes and technical change. Partly as a result of this, the influence of technical change on the demand for the variable input, the output supply, and the demand for capital is important. However, the price elasticities of the output and the variable input are small, even in the long-run.

5.1 Introduction

Models of output supply and input demand can be grouped into three categories. The first, and most popular (see Chapters 2 and 3), starts from the assumption that the firm's objective is to maximize short-run profits. The firm is in static equilibrium with respect to outputs and a subset of inputs (the variable inputs) that is conditional on the level of the remaining inputs (fixed inputs). The second category of model relies on the assumption that there are no fixed inputs: the firm is in (full) static equilibrium with respect to outputs and all the inputs. The third category of model is a dynamic factor demand model. It is assumed that some of the inputs on the farm are quasi-fixed; these are the inputs which can adjust only at some cost. The presence of a quasi-fixed input is an important source of imperfect adjustment in the short-run. Durable inputs such as capital are most likely to contribute to this form of costly and slower response by producers. The cost of adjusting the capital stock implies that the short-run price elasticities of the output and inputs are lower than the long-run price elasticities.

Most of the empirical literature on dynamic factor demand models lacks a sound theoretical basis. For example Jorgenson and Siebert (1968) append an ad hoc structure to a theory of static profit maximization to generate an investment demand function. The developments in the adjustment cost model of a firm (Lucas, 1967; Treadway, 1969) have provided a consistent, dynamic, theoretical framework for the determination of all inputs and outputs. Epstein (1981b) developed a dual approach that permits the firm's behavioural equations to be derived directly from a well behaved optimal value function. However this dual approach is only useful at the aggregate level, because it can only be applied if investments exceed zero (Epstein, 1981b: 91). Denny, Fuss and Waverman (1981), Lopez (1985) and Vasavada and Chambers (1986) have estimated models that are fully consistent with adjustment cost theory. Denny et al. and Lopez use the primal approach, aggregated data, and distinguish only one capital good. Vasavada and Chambers use the dual approach, aggregated data, and distinguish four quasi-fixed inputs.

In this chapter the short-run, intermediate-run, and long-run price elasticities of the output and inputs in agriculture will be investigated, using a model of factor demand. The theoretical model developed is mainly derived from Lucas. In contrast to previous studies, panel data are used. Because panel data are used, the dual approach is not applicable: investments measured at the farm level are sometimes zero.

Annual data from dairy farms over the period 1970-1982 were used for estimation of the model. The farms usually remain in the panel for about five years; the data set forms an unbalanced panel. Instrumental variable methods, based on first differences of the variables, were used to estimate the model.

An important assumption of the adjustment cost model used, is that expectations of the relevant prices are static. This is not an unreasonable assumption for the Dutch dairy sector (see Chapter 6). The advantage of assuming static expectations is that a completely consistent system of a profit function, a demand function for variable inputs, and a demand function for the quasi-fixed input can be estimated using cross-equation restrictions on the parameters. In models that assume rational expectations and solve the stochastic control problem, only demand functions for quasi-fixed inputs can be estimated (Kodde et al., 1990).

The chapter is organized as follows. In Section 5.2 the theoretical model is derived in an informal way; the emphasis is on the economic interpretation. The specification of the model is presented in Section 5.3 as well as the formulas for price elasticities. The data and the estimation method used are described in Section 5.4. In Section 5.5 the empirical results are discussed. The most important conclusions are summarized in Section 5.6.

5.2 Theoretical model

Consider a farm family which maximizes the present value of income over an infinite horizon with respect to two inputs: a variable input (mainly feed) and a quasi-fixed input (livestock, buildings and equipment). In addition to the variable input and the quasi-fixed input two fixed inputs are distinguished: labour and land.[1] The farm family is a price-taker in the output and variable input markets, a reasonable assumption using data from Dutch dairy farms.

The farm's objective can be seen as first having to maximize short-run profits with respect to the variable input and then maximizing the present value of its long-run profits. Therefore the short-run profit is conditional upon a fixed level of the capital stock, just as in the Chapter 2, 3 and 4. According to duality theory, the short-run optimizing behaviour of farmers constrained by technology can be represented equivalently by a profit function. If the profit function satisfies certain regularity conditions, it is dual to the production function and its parameters contain sufficient information to describe the farm's production technology at profit-maximizing points in the set of production possibilities. Testable conditions of regularity are: the profit function decreases in the price of the input; increases in the price of the output; is convex in all prices; is linearly homogeneous in prices; increases and is concave in the quasi-fixed input. The profit function is normalized by the price of the output, to ensure that it is linearly homogeneous in prices.

The farm family faces adjustment costs when it alters its stock of quasi-fixed input. Changes in this capital stock imply increasing costs because new capital is integrated into a going concern. Reorganizing the production method is an example of such a cost, as are the learning processes of the farm family members. The important issues are that all these additional costs are endogenous and transient, take place mainly during the period in which the new investment is undertaken and that the marginal costs usually increase concomitantly with the magnitude of investment. In line with the literature on dynamic factor demand models (e.g. Nickell (1986)) a quadratic functional form is assumed. Adjustment

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[1] The labour input (mainly family labour) is not very sensitive to price changes; see Chapter 4. Therefore, we assume that labour is exogenous. The changes in the amount of land per farm are very sensitive to the availability of land near the farm. No information is available about the latter. Therefore, land is also treated as an exogenous variable.

costs imply that input adjustments are sluggish, since it is costly to change stocks quickly rather than slowly. Such sluggishness could be construed as a form of asset fixity. Low resource returns follow, because an element of the opportunity cost of a quasi-fixed factor is its marginal adjustment cost.

The farm family's expectations regarding the evolution in prices of inputs and output and in the fixed inputs are static: therefore their expectations for the relevant price variables and fixed inputs are fixed at the current level for all future periods. The actual optimal input decisions at time t do not move over time unless actual prices and actual fixed inputs change. This assumption may not be as restrictive as it appears, because farmers adjust their plans (and hence their targets) every year as prices and fixed inputs change.

The intertemporal profit-maximizing problem of farm h is, therefore, equal to maximizing the present value of the difference between the short-run profits, adjustment costs and capital costs[2]:

$$\text{Max} \int_0^{\infty} 0 \; [\pi(p,k,l,g,t) - \tfrac{1}{2} \gamma \dot{k}^2 - u(r+\delta)k \;] \; e^{-rt} dt \tag{5.1}$$

where π is the profit normalized by the price of the output; p is the ratio of the price of the variable input to the price of the output; k is the level of the capital stock; $\dot{k}$ is the net capital investment; l is labour; g is land; t is technology; u is the asset price of capital (corrected for investment subsidies) normalized by the output price; δ is the rate of depreciation of capital; γ is the adjustment cost parameter ($\gamma > 0$); and r is the real discount rate. Using Euler's equation of the calculus of variation, the first order condition of problem (5.1) for the quasi-fixed input is:

$$u(r+\delta) + r\,\gamma\,\dot{k} - \gamma\,\ddot{k} = \pi_k \tag{5.2}$$

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[2] Maximizing the present value of the difference between the short-run profits, adjustment costs and capital costs is equivalent to maximizing the present value of the difference between short-run profits, depreciation costs, adjustment costs and costs of investment (Lawrence, 1990: 384-385).

where π_k is the first derivative of the profit function to k and $\ddot{k}$ is the derivative of the net capital investment to time. It will be convenient to interpret (5.2) in its integral form, which can be obtained by direct integration[3]:

$$u(r+\delta)/r + \gamma\,\dot{k} = \int_t^{\infty} e^{-r(s-t)}\pi_k \, ds \tag{5.3}$$

The left-hand side of the equation is the marginal cost of investment at time t, which consists of two components: the present value of the capital costs of one unit of the capital good and the marginal adjustment cost of investment, which take place during the period in which the investment is undertaken. The right-hand side of the equation gives the marginal present value of investment at time t, an integral of discounted marginal profits of the asset k. Condition (5.3) thus prescribes that investment be carried out to the point where its marginal cost is equated to its marginal present value.

The right-hand side of equation (5.3) is a function of the complete time path of the capital stock. One of the factors this time path depends upon is the current rate of investment. The left hand-side of equation (5.3) is a function of that rate. Equation (5.3), therefore, does not give a useful decision rule for determining the current level of investment (Nickell, 1978:29).[4]

The solution proposed by Lucas (1967) was to link this model to the literature on ad hoc partial adjustment. The firm partly adjusts the capital stock towards the 'desired' capital stock k^* at a rate which is directly related to the difference between the desired stock and the actual stock. The desired capital stock is given by the long-run equilibrium. In the long-run equilibrium $\dot{k} = \ddot{k} = 0$, and therefore the first order condition in equilibrium becomes:

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[3] The left hand side has been obtained by taking the integral of the left hand side of equation (5.2). The same approach has been used by Treadway (1971: 848), only he ignores depreciation costs.

[4] In a rational expectations framework it is possible to use the Euler equation to derive an estimable demand function for capital (see Chapter 6, equation (6.11)).

$$\pi_k^* = u(r+\delta) \tag{5.4}$$

where π_k^* is the first derivative to k at the optimal stock. Note that equation (5.4) is the well-known condition for the marginal return to capital to be equal to the user cost of capital.

In order to derive a demand function for the capital good, following Lucas, equation (5.2) is linearly approximated around the long-run optimal capital stock k^*. Equation (5.2) can be written as:

$$f(k,\dot{k},\ddot{k}) = u(r+\delta) + r\,\gamma\,\dot{k} - \gamma\,\ddot{k} - \pi_k = 0 \tag{5.5}$$

and can be linearly approximated around $(k^*, \dot{k}^* = 0, \ddot{k}^* = 0)$. Using a Taylor expansion this gives:

$$-\gamma\,\ddot{k} + r\,\gamma\,\dot{k} - \pi_{kk}\,(k - k^*) = 0 \tag{5.6}$$

where π_{kk} is evaluated at k^*. Equation (5.6) is a second order differential equation which can be solved for its stable root, to yield a useful decision rule for investment:

$$\dot{k} = m\,(k^* - k) \tag{5.7}$$

where $m = -\frac{1}{2}\{r - [r^2 + 4\pi_{kk}/\gamma]^{\frac{1}{2}}\}$ and k^* is the optimal long-run capital stock that solves equation (5.4).

Because discrete annual changes will be used in the empirical analysis, it is more convenient to rewrite equation (5.7) as demand function for capital:

$$k_{t+1} = m\,k_t^* + (1 - m)\,k_t \tag{5.8}$$

The adjustment rate (m) is rarely a fixed parameter. It depends on the discount rate (r), on the parameters and variables determining the short-run profit function π and the adjustment cost parameter (γ). However, when panel data are used, it is necessary to assume that the adjustment rate is constant over time. This will be explained in Section 5.4. The adjustment rate can easily be shown to be negatively related to the discount rate, that is, $\partial m/\partial r < 0$. Higher discount rates reduce the speed of adjustment of the capital stock to desired levels. Another important aspect is that the adjustment rate should be less than or equal to one (instantaneous adjustment to optimal levels) and greater than zero. A necessary and sufficient condition for this is $0 \leq -\pi_{kk}/\gamma \leq 1+r$. Finally, the adjustment rate can be used to trace how long it takes k to become nearly as great as k^*.

We have now derived a completely consistent dynamic equation system of factor demand. The model includes the demand function for capital (equation (5.8)), the short-run profit equation, and the related short-run variable input demand equation. By specifying an appropriate functional form for π, an explicit representation for the demand function for the variable input can be obtained by Hotelling's Lemma. From this model the expressions for short-, intermediate-, and long-run own-price, cross-price, and fixed inputs elasticities that completely summarize the dynamic time paths of output supply and input demands can be derived. In particular, following the Marshallian tradition, short-run elasticities can be defined as those obtained if the capital stock is fixed, intermediate-run as the impact if the capital stock has adjusted partially, and long-run as the response if the capital stock has adjusted fully to the optimal level.

5.3 Specification of the model

For empirical analysis the quadratic function, which is a flexible functional form, is chosen as an approximation to the true profit function. There are three reasons for choosing this approximation. First, using a quadratic form means that the linear approximation of the first order condition (5.6) is exact. Second, functions for output supply, the demand for variable inputs and the optimal capital stock can be specified explicitly. Third, theoretical restrictions imposed on the profit function can easily be introduced and tested because the second-order partial derivatives are constants. The intercepts of the profit function, the demand function for the variable inputs, and the demand function for capital vary over the farms. This intercept reflects differences across farms, e.g. in management and land quality.

The normalized short-run profit function for farm h is written as:

$$\pi_h = \alpha_{0h} + \alpha_1 p + \sum_{i=2}^{5} \alpha_i x_{ih} + \tfrac{1}{2} \alpha_{11} p^2 + \sum_{i=2}^{5} \alpha_{1i}\, p\, x_{ih} + \tfrac{1}{2} \sum_{i=2}^{5} \sum_{j=2}^{5} \alpha_{ij}\, x_{ih} x_{jh} \tag{5.9}$$

where $\alpha_{ij} = \alpha_{ji}$; x_i are the inputs (with i = 2 or l (labour), 3 or k (capital), 4 or g (land), 5 or t (technology)). By Hotelling's Lemma, if we differentiate the normalized short-run profit function to the normalized price, we obtain the demand function for the variable input (v):

$$v_h = -\alpha_{1h} - \alpha_{11}\, p - \alpha_{12}\, l_h - \alpha_{13}\, k_h - \alpha_{14}\, g_h - \alpha_{15}\, t \tag{5.10}$$

Using equation (5.4), the long-run optimal capital stock, k_h^*, can be derived from (5.9):

$$k_h^* = \frac{1}{\alpha_{33}} \cdot [\, u(r+\delta) - \alpha_{3h} - \alpha_{31}\, p - \alpha_{32}\, l_h - \alpha_{34}\, g_h - \alpha_{35}\, t \,] \tag{5.11}$$

Using equation (5.8) the demand function for capital at the end of period t is:

$$k_{t+1,h} = \frac{m}{\alpha_{33}} \cdot [\, u_t(r+\delta) - \alpha_{3h} - \alpha_{31}\, p_t - \alpha_{32} l_{t,h} - \alpha_{34} g_{t,h} - \alpha_{35} t \,] + (1-m)\, k_{t,h} \tag{5.12}$$

where $m = -\tfrac{1}{2}\{r - [r^2 + 4\alpha_{33}/\gamma]^{\frac{1}{2}}\}$ is the adjustment rate.

A set of short-run (SR), intermediate-run (IR), and long-run (LR) elasticities for the own-, cross-price, and fixed inputs elasticities will be derived from the parameters of the estimating system. Output supply (q) elasticities can be derived using the definition of the normalized profit ($\pi_h = q_h - p\, v_h$).

Short-run responses of the variable input demand, output supply and profit are given by[5]:

[5] The index h has been removed to improve the readability of the formulae.

$$\frac{\partial v}{\partial p} = -\alpha_{11} \text{ and } \frac{\partial v}{\partial x_i} = -\alpha_{1i}\ ,\ i = l,k,g,t \tag{5.13}$$

$$\frac{\partial q}{\partial p} = -\alpha_{11}p \text{ and } \frac{\partial q}{\partial x_i} = \alpha_i + \alpha_{i2}l + \alpha_{i3}k + \alpha_{i4}g + \alpha_{i6}t,\ i=l,k,g,t \tag{5.14}$$

$$\frac{\partial \pi}{\partial x_i} = \alpha_i + \alpha_{i1}p + \alpha_{i2}l + \alpha_{i3}k + \alpha_{i4}g + \alpha_{i6}t,\ i=p,l,k,g,t \tag{5.15}$$

The above short-run price responses give the responses to the price of the variable input. Short-run responses to the output price can easily be obtained, because the demand function for the variable input and the output supply function are homogeneous of degree zero in prices and the profit function is linearly homogeneous in prices.

The short-run elasticities of the capital good are zero. The demand for capital responses to changes in prices and fixed inputs after one year are:

$$\frac{\partial k_{t+1}}{\partial k_t} = (1-m) \text{ and } \frac{\partial k_{t+1}}{\partial x_{t,i}} = m\,\frac{\partial k_t^*}{\partial x_{t,i}},\ i=p,l,g,t,u(r+\delta) \tag{5.16}$$

where:

$$\frac{\partial k^*}{\partial u(r+\delta)} = \frac{1}{\alpha_{33}} \text{ and } \frac{\partial k^*}{\partial x_i} = -\frac{\alpha_{3i}}{\alpha_{33}}\ ,\ i=p,l,g,t \tag{5.17}$$

If the variable input and capital are substitutes ($\alpha_{13} > 0$): the relation between the amount of capital and the demand for the variable input is negative, see equation (5.13). Because of the cross-equation symmetry restrictions of the coefficients ($\alpha_{13} = \alpha_{31}$) and the concavity of the profit function in capital ($\alpha_{33} < 0$), the relation between the demand for capital and the price of the variable input is positive, see equations (5.16) and (5.17). The opposite holds if the capital good and the variable input are complements.

Intermediate-run (three years) responses of variable input demand, output supply and profit to changes of prices and fixed inputs along the optimal path are given by:

$$\frac{\partial y^{IR}}{\partial x_i} = \frac{\partial y^{SR}}{\partial x_i} + \frac{\partial y^{SR}}{\partial k}\frac{\partial k^{IR}}{\partial x_i} \quad y = v,q,\pi \quad \text{and } i{=}p,l,g,t,u(r+\delta) \tag{5.18}$$

That is, the intermediate-run response is equal to the short-run response plus the change in v, q or π induced by the change in the capital stock associated with the variation in the exogenous variable. The intermediate-run (three years) responses of the demand for capital stock are given by:

$$\frac{\partial k^{IR}}{\partial x_i} = m\frac{\partial k^*}{\partial x_i} + (1-m)m\frac{\partial k^*}{\partial x_i} + (1-m)^2 m\frac{\partial k^*}{\partial x_i}, \quad i{=}p,l,g,t,u(r+\delta) \tag{5.19}$$

The elasticities of the optimal capital stock are derived from equation (5.17). The long-run elasticities of output supply, demand for the variable input, and profit can be calculated using equation (5.18), substituting the long-run response of the demand for capital. The long-run response of the demand for capital is equal to equation (5.19) with $m = 1$.

We will now demonstrate that the own-price elasticities of the demand for the variable input satisfy the Le Chatelier principle (if the profit function is well behaved): that is the absolute value of the long-run elasticity exceeds the intermediate-run elasticity which, in turn, exceeds the short-run elasticity. The short-run response is equal to $-\alpha_{11}$, which is smaller than zero because the profit function is convex in the normalized price. The intermediate-run response of the demand for the variable input is equal to:

$$\frac{\partial v^{IR}}{\partial p} = -\alpha_{11} + \frac{\alpha_{13}^2}{\alpha_{33}}[m + (1-m)m + (1-m)^2 m] \tag{5.20}$$

This response is smaller than $-\alpha_{11}$, because α_{33} is smaller than zero when the profit function is concave in the capital stock. In the long-run ($m=1$) the elasticity is even smaller.

We do not obtain such an unambiguous result for the own-price elasticities of the output supply. It can be shown that if α_{13} is smaller than zero (the capital good and the variable input are complements), then the Le Chatelier principle is satisfied. However, if α_{13} is positive (the capital good and the variable input are substitutes), the size of the parameters determines whether or not the Le Chatelier principle is satisfied.

Cross-price elasticities and elasticities for fixed inputs are allowed to 'overshooting' (i.e. short-run elasticities may exceed the magnitude of intermediate-run and long-run elasticities).

5.4 Data and estimation

The data used in this study are from a sample of Dutch farms that keep accounts of their farming for the Agricultural Economics Research Institute. Annual data from dairy farms over the period 1970-1982 were used to estimate the model. The farms usually remain in the panel for about five years; the data set forms an unbalanced panel. The sample used involved 1574 observations and 554 different farms.

Four inputs were included in the profit function: labour in hours (family and hired labour), capital (livestock, buildings and machinery), land in hectares, and a normalized price (the ratio of the Törnqvist price index of the variable input to the Törnqvist price index of the output). Implicit quantity indices for the output, the variable input and capital were obtained as the ratios of the value to the Törnqvist price index. The Törnqvist price index differs over the years, not over the farms. The quality differences in the output, the variable input, and the capital good between farms are, therefore, reflected in quantity differences between farms. The amount of family labour is the calculated remuneration of family labour divided by the hourly wage costs of a farm worker. The hours worked by children are calculated as having a smaller remuneration than the hours worked by the farmer; therefore the total hours worked by the farm family is in some degree corrected for differences in the quality of labour on the farm. No adjustment was done for differences in the quality of labour and land across farms. These differences are taken into into account by varying the intercepts of the estimated equations over the farms. Normalized profit is defined as the value of output minus the value of variable input divided by the Törnqvist price index of output. The prices of machinery and building capital are corrected for investment subsidies. The costs of capital are composed of discount costs and depreciation costs, see Appendix A. The discount rate in the adjustment rate is assumed to be equal to 0.03. Values of the volume of capital at the beginning and end of the period are used. Section 1.3 and Appendix A give a complete description of the data.

Because profits of the dairy sector are strongly influenced by the weather, a weather index with parameter α_w was added to the profit function. A meteorological model was used to calculate the weather indices (Oskam and Reinhard, 1992).

A dynamic factor demand model was developed. Additive error terms were added to the equations because:
- farmers are profit maximizers but they will not always succeed in choosing levels of output and inputs that will lead to a maximum level of profit;
- the quadratic functional form is an approximation of the true underlying short-run profit function and the true underlying adjustment cost function.

The equations contain farm-specific effects. The demand equation for capital for farm h at year t is of the form:

$$k_{t+1,h} = \mu_h + (1-m)k_{t,h} + v'z_{t,h} + e_{t+1,h},\ h=1\ldots H,\ t=1\ldots T \qquad (5.21)$$

where k_{t+1} is the capital stock at the end of period t; z is a K vector of explanatory variables; μ_h is the specific effect (fixed or random) of farm h representing the effects of those variables peculiar to the hth individual in more or less the same fashion over time; v is a K vector of parameters; H is the number of farms; T is the number of time-series observations; e is the error term which represents the effects of the omitted variables that are peculiar to both the individual units and time periods. We assume that $e_{t,h}$ can be characterized by an independently identically distributed random variable with mean zero and variance σ_e^2.

If the farm-specific effects are fixed, the fixed effects estimator is no longer consistent in the typical situation in which a panel contains a large number of individuals, for only a short period of time. If the farm-specific effects can be treated as random, the consistency of the maximum likelihood estimator and the interpretation of the model depend on the assumption about the initial observations (Hsiao, 1986). One important assumption that must be made for the random effects estimator to be consistent is that the individual effect is independent of the regressors. Doubts have been raised about this assumption in a static model, see Chapter 3. Instrumental variable methods can be used to obtain an estimator that overcomes these problems.

Taking first difference of equation (5.21) to eliminate μ_h, we have:

$$(k_{t+1,h} - k_{t,h}) = (1-m)(k_{t,h} - k_{t-1,h}) + v'(z_{t,h} - z_{t-1,h}) + (e_{t+1,h} - e_{t,h}) \qquad (5.22)$$

Because $(k_{t,h} - k_{t-1,h})$ correlates with $(e_{t+1,h} - e_{t,h})$ an instrument variable method must be used to obtain a consistent estimator. Although $k_{t-1,h}$ correlates with $(k_{t,h} - k_{t-1,h})$ it does not correlate with $(e_{t+1,h} - e_{t,h})$, therefore $k_{t-1,h}$ is a valid instrument. The other instruments used are: the first differences of the exogenous variables in the model; the exogenous variables in the model lagged by one year; the age of the farmer; and the farm size. The resulting instrumental variable estimator is consistent when $H \rightarrow \infty$ or $T \rightarrow \infty$, or both. The variance of this estimator is only consistent when $T \rightarrow \infty$ (Anderson and Hsiao, 1981).

It is assumed that the adjustment rate (m) is constant over time. This assumption is necessary because otherwise the parameter of $k_{t,h}$ in equation (5.21) would vary over time and first differencing of equation (5.21) would result in an equation that has a time varying parameter and is difficult to estimate.

Because of the cross-equation symmetry restrictions, the possibility that the error terms of the functions (the profit function, the demand function for the variable input and the demand function for capital) may be correlated, and the previously mentioned correlation between the first difference of the capital stock and the error term, 3SLS (Judge et al., 1985: 599) is an appropriate technique for estimating the model in first differences. The endogenous variables are: $\pi_t - \pi_{t-1}$, $v_t - v_{t-1}$, $k_{t+1} - k_t$, $k_t - k_{t-1}$, $(k_t p_t - k_{t-1} p_{t-1})$, $(k_t x_{jt} - k_{t-1} x_{j,t-1})$ $(j = k,l,g,t)$. The instruments used are: k_{t-1}, $k_{t-1} p_{t-1}$, $k_{t-1}\ x_{j,t-1}$ $(j = k,l,g,t)$; first differences of the exogenous variables in the model; the exogenous variables in the model lagged by one year; the age of the farmer; and the farm size.

The independence of the first difference of the capital stock and the error term is tested using a Hausman test. To implement the Hausman test two estimators have to be constructed. Assuming that the first difference of the capital stock is uncorrelated with the error term, SUR (Judge et al., 1985:467) is an appropriate estimation technique. This estimator is consistent and efficient under the null hypothesis that the first difference of the capital stock and the error term are independent. The 3SLS estimator described earlier is a consistent estimator, when the first difference of the capital stock and the error term are not independent. The Hausman test can easily be implemented using these estimators and the corresponding variance matrices (Maddala, 1989:435-436).

5.5 Results

The parameters of the models estimated using 3SLS are presented in Table 5.1.[6] The consistency of the SUR estimator is tested using a Hausman test. The Hausman test statistic has asymptotically a χ^2 distribution with 22 degrees of freedom. The test statistic is equal to 163.2, which is significant at the 1% level. Therefore, independence of the first difference of the capital stock and the error term is rejected and SUR is not an appropriate estimation technique.

Table 5.1 Parameter estimates of the normalized profit equation and the demand equation for the variable input*

Parameter	Coefficient	Standard error	Parameter	Coefficient	Standard error
α_p	- 0.837	0.116	α_{lk}	0.002	0.007
α_l	0.068	0.049	α_{lg}	0.018	0.014
α_k	0.161	0.051	α_{lt}	0.002	0.004
α_g	0.311	0.094	α_{kk}	- 0.067	0.014
α_t	0.057	0.026	α_{kg}	0.067	0.019
α_{pp}	0.033	0.057	α_{kt}	0.024	0.006
α_{pl}	- 0.014	0.008	α_{gg}	- 0.151	0.042
α_{pk}	- 0.123	0.012	α_{gt}	- 0.013	0.009
α_{pg}	0.028	0.018	α_{tt}	- 0.010	0.003
α_{pt}	- 0.020	0.005	α_w	0.506	0.092
α_{ll}	- 0.016	0.009	γ	0.886	0.364

* The subscripts p, l, k, g, t, w refer to normalized price, labour, capital, land, technology, and weather, respectively.

Nine of the twenty-two parameters are not significant at the 5% level. However, care should be taken not to base any far-reaching conclusion on the significance or non-significance of parameters. The profit function is

[6] In estimating the model some of the variables were transformed: labour is in 1000 hours; land in 10 hectares; profit, variable input and capital in 100 000 guilders of 1980.

non-linear in variables, so that one cannot generally associate a parameter with a particular variable, as in a linear model. This is why elasticities of profit, output supply, variable input demand and demand for capital with respect to prices and inputs were calculated.[7]

Before calculating the elasticities of prices and inputs it is important to test the basic assumption underlying the methodology used in this study: i.e. that farmers are profit-maximizers. For testing the assumption of monotonicity, elasticities for the profit function were calculated using the estimated parameters, see Table 5.2. As can be concluded from Table 5.2, the normalized short-run profit function decreases in the price of the input and increases in the price of the output and the fixed inputs. According to Table 5.1 the normalized short-run profit function is convex in the normalized price ($\alpha_{pp} > 0$) and concave in capital ($\alpha_{kk} < 0$). The assumption of short-run profit maximization behaviour is, therefore, not rejected by the data. The adjustment cost parameter γ is significant and equals 0.89, the adjustment costs are approximately 5% of the total costs of capital. Adjustment costs play an important role in determining intermediate-run output supply and factor demand responses. That is, this allows us to statistically reject the hypothesis of instantaneous capital adjustments prevalent in static models.

Using the estimates of γ and α_{kk} the adjustment rate m is equal to 0.26 and is very significant; the standard deviation is equal to 0.05. This result is remarkably similar to the result obtained by Vasavada and Chambers (1986); using aggregate data of U.S. agriculture over the period 1947-1979 they found an adjustment of 26% for capital during the first year. Lopez (1985) obtained an adjustment rate of 0.45, using aggregate data for the Canadian food processing industry. Stefanou et al. (1992) obtained an adjustment rate of about 0.5, using data from average farms in the German dairy sector over the period 1982-1985. Kuiper and Thijssen (1991) obtained an adjustment rate of 0.17, using aggregate data for Dutch agriculture.

The short-run elasticities of prices and inputs were calculated for the profit function, the demand function for the variable input, the supply

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[7] An interesting R^2 of the estimated functions is based on the residual sum of squares of equation (5.21). However, in contrast to a model using the fixed effects estimator, in a model estimated in first differences, this residual sum of squares cannot be calculated. An indication of the R^2 is obtained by estimating the functions with an intercept that is the same for all farms. The R^2 of the profit function is 0.88; the R^2 of the demand function for the variable input is 0.77; and the R^2 of the demand function for capital is 0.93.

function of the output and the demand function for capital, using equations (5.13), (5.14), (5.15), (5.16) and (5.17). The variances of these elasticities (e) are calculated in an appropriate way by[8]:

$$S_e = \left[\frac{\partial e}{\partial c}\right]' \Omega \left[\frac{\partial e}{\partial c}\right] \tag{5.23}$$

where c is a vector of the parameters of the model and Ω is the covariance matrix of the estimators of these parameters.

As can be concluded from Table 5.2, the own price elasticity of the demand for the variable input is small: -0.03. The own price elasticity of the output is even smaller: 0.01. Both elasticities do not differ significantly from zero. As a result of the homogeneity restriction, the cross-price elasticities are the opposite of these elasticities. The output price elasticity of the demand for the capital good is the opposite of the sum of the price elasticities of the capital costs and the input price, because all prices are normalized by the output price.

The variable input and capital are complements, i.e. there is a positive relation between the amount of capital and the demand for the variable input: elasticity is 0.57. Because of the cross-equation symmetry restrictions of the parameters ($\alpha_{13} = \alpha_{31}$) and the concavity of the profit function in capital ($\alpha_{33} < 0$), the elasticity of the demand for capital for the price of the variable input is negative: -0.10. Land and the variable input are substitutes. The relation between the output supply and the amount of land is positive.

The large influence of technical change on the input and the output is remarkable. The variable input grows by 2.2% per year because of technical change. This increased demand for the variable input is caused by new breeding techniques that result in cows with a larger feed intake, and there was a transition from roughage to concentrates. The influence of technical change on the supply of the output is even larger: 2.5% per year.

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[8] See Rao (1973:383-389). To calculate the standard errors of the elasticities, derivations from the equations (5.13), (5.14), (5.15), (5.16) and (5.17) were worked out.

Table 5.2 Short-run elasticities of profits, the demand for the variable input and the output supply, and elasticities of the demand for capital for a term of one-year, at the sample mean (standard errors in parentheses)

	Price output	Price input	Capital	Land	Labour	Technical change	Capital costs
Profit	2.13 (0.07)	-1.13 (0.07)	0.44 (0.12)	0.45 (0.07)	0.18 (0.05)	0.028 (0.007)	
Variable input	0.03 (0.06)	-0.03 (0.06)	0.57 (0.06)	-0.07 (0.05)	0.07 (0.04)	0.022 (0.006)	
Output	0.01 (0.02)	-0.01 (0.02)	0.50 (0.07)	0.24 (0.04)	0.14 (0.03)	0.025 (0.005)	
Capital	0.15 (0.04)	-0.10 (0.03)	0.70 (0.05)	0.14 (0.03)	0.01 (0.03)	0.021 (0.005)	-0.05 (0.01)

The short-run elasticities for prices, capital and land differ from the results given in Chapter 3 (p.44): the elasticities for prices and capital are larger, the elasticities for land are smaller. But the elasticities for labour and technical change given in Chapter 3 do not differ significantly from the results in this chapter. Possible reasons for the discrepancy are: in Chapter 3 a fixed effect estimator (which is more efficient than taking first differences) was used; in this study a dynamic model was estimated with cross-equation restrictions on the parameters.

The elasticity for the capital stock, lagged by one year in the demand function for capital, is 0.70. This results in the already described adjustment parameter of 0.26. There is almost no relation between capital and labour. This is probably caused by counteracting elements between these factors. For example, an increase in family labour can allow herd size to increase, but it can also replace machinery. Labour and capital are complements, as are land and capital. This is a plausible outcome for Dutch dairy farms. The influence of technical change on the demand for capital is very important.

The gross investments in the capital stock equal 10% of that stock. Therefore, the short-run (one-year) elasticities of the investments are ten times the elasticities of the capital stock. Investments are sensitive to: changes in the price of the output; changes in the price of the variable input; capital costs; changes in the area of land farmed; and technical change. Investment subsidies are, therefore, useful incentives if the investments have to be stimulated.

Equations (5.18) and (5.19) were used to calculate intermediate-run and long-run elasticities for prices and fixed inputs (see Table 5.3). The elasticities can be defined as short-run as if obtained if the capital stock is fixed; intermediate-run as the impact if the capital stock has adjusted partially; and long-run if the capital stock has adjusted fully to the optimal level. Capital is sensitive to price changes, changes in the area of land, and technical change; therefore there are sizeable differences between short-run elasticities and intermediate-run elasticities.

With regard to the own-price elasticities of the output supply the Le Chatelier principle is satisfied, because α_{13} is smaller than zero (the capital good and the variable input are complements).

The price elasticities of the variable input and the output rise considerably in comparison to the short-run elasticities, but remain small. This is because (see equations (5.18) and (5.19)):

- the elasticity of output supply and variable input demand with respect to capital are only 0.50 and 0.57, respectively.
- the coefficient for capital in the estimated demand function for capital is relatively small: 0.74. In models where no fixed effects are taken into account, this coefficient is almost one. Therefore, the differences between the short-run and the long-run price elasticities of the capital stock with respect to the prices are not very large; compare Table 5.2 with 5.3.
- investments are very sensitive to changes in prices. However, the elasticities of the capital stock are only 0.34 for the output price and -0.23 for the price of the variable input over a period of three years.

Elasticities of the demand for the variable input, profits and output supply for the capital costs are zero in the short-run. In the intermediate-run and long-run, capital stock adjusts and, because the variable input and capital are complements, there is a negative relation between the capital costs and the demand for the variable input, profits and output supply.

The variable input and land are substitutes in the short-run; elasticity is -0.07. The intermediate-run elasticity is 0.10, indicating that the variable input and land are complements. This is because the variable input and capital are complements (the short-run elasticity is 0.57), as are capital and land (the intermediate-run elasticity is 0.30). Using equation (5.18) this results in $-0.07 + 0.57 * 0.30 = 0.10$.

Table 5.3 Intermediate-run (three years) elasticities and long-run elasticities at the sample mean (standard errors in parentheses)

	Price output	Price input	Land	Labour	Technical change	Capital costs
Profit						
- intermediate-run	2.28	-1.23	0.58	0.19	0.048	-0.05
	(0.08)	(0.08)	(0.08)	(0.06)	(0.007)	(0.02)
- long-run	2.36	-1.28	0.65	0.20	0.059	-0.08
	(0.09)	(0.08)	(0.09)	(0.07)	(0.008)	(0.02)
Variable input						
- intermediate-run	0.23	-0.16	0.10	0.08	0.049	-0.07
	(0.08)	(0.07)	(0.07)	(0.06)	(0.008)	(0.02)
- long-run	0.33	-0.23	0.19	0.08	0.063	-0.10
	(0.09)	(0.09)	(0.08)	(0.07)	(0.009)	(0.03)
Output						
- intermediate-run	0.18	-0.13	0.39	0.15	0.049	-0.06
	(0.05)	(0.04)	(0.06)	(0.05)	(0.006)	(0.02)
- long-run	0.27	-0.18	0.46	0.15	0.061	-0.09
	(0.07)	(0.06)	(0.07)	(0.06)	(0.008)	(0.03)
Capital						
- intermediate-run	0.34	-0.23	0.30	0.02	0.047	-0.12
	(0.08)	(0.06)	(0.06)	(0.06)	(0.009)	(0.03)
- long-run	0.52	-0.34	0.46	0.03	0.071	-0.18
	(0.11)	(0.08)	(0.08)	(0.09)	(0.009)	(0.04)

The influence of technical change on the demand for the variable input, the output supply and the demand for capital is very important. If capital is fully adjusted to the optimal level, the variable input and the output grow by 6% per year, because of technical change.

When these results are compared with results from other studies we find that the estimates of the price elasticities presented in Table 5.3 are low. Starting from decision models, using aggregate data from the Dutch dairy sector over the period 1969-1984, Roemen (1990) obtained an own-price long-run elasticity of milk of 0.94. Oskam and Osinga (1982) obtained an own-price long-run elasticity for milk of 1.33, using aggregate data from the Dutch dairy sector over the period 1959-1979. The influence of technical change on the supply of the output obtained by Oskam and Osinga (1982) is equal to 6.5% in the long-run, a result that is remarkably similar to the result of our study.

5.6 Conclusions

In this chapter a dynamic equation system of factor demand was estimated using an incomplete panel. The system is based on Lucas' classical contribution concerning the investment decision of a firm facing adjustment costs when it alters its stock of capital. The main conclusions obtained from the study are

(a) The postulated model seems to provide an appropriate description of Dutch dairy farmers' decisions about the demand for the variable input, profit, output supply, and the demand for capital, because its underlying assumptions are not rejected by the data and the elasticity estimates are reasonable.

(b) Because panel data are available one may allow for the possibility that the intercepts in the profit function, the demand function for the variable input and the demand function for capital vary over farms. The fixed effects estimator is, however, not consistent for dynamic models. Therefore, it is necessary to use an instrumental variable estimator, based on the first differences of the variables.

(c) Capital adjustment costs play a substantial role in determining short-run and intermediate-run behavioural responses. The hypothesis of instantaneous capital adjustment to changing prices is statistically rejected. The adjustment rate to the optimal level is equal to 26% per year.

(d) Investments are very sensitive to changes in the price of the output, changes in the price of the variable input, changes in capital costs, and technical change. Price policy is, therefore, a useful instrument to influence investment behaviour. In contrast with changes in the amount of labour, changes in the area of land farmed have important effects on the investment behaviour of farmers.

(e) The influence of technical change on the demand for the variable input, the output supply and the demand for capital is very important. If capital is fully adjusted to the optimal level, the variable input and the output growth rate is about 6% per year, because of technical change.

(f) The price elasticities of the output and the variable input are very small in the short-run, and remain small in the intermediate-run and even in the long-run. Agricultural price policies and environmental policies are therefore likely to have only limited success, even in the long-run, in influencing the level of output supply and variable input demand via levies or subsidies.

CHAPTER 6

STATIC OR RATIONAL EXPECTATIONS?

Demand functions for capital are estimated using an incomplete panel of Dutch dairy farms. Two forms of farmers' expectations regarding the future path of prices and fixed inputs are used; static expectations and rational expectations.

The model based on static expectations fits the data well. Investments are very sensitive to changes in price and technology. However, the price elasticity of the output is low, even in the long-run. The results obtained from the rational expectations model are not consistent with the theory.

6.1 Introduction

In this chapter the intermediate-run and long-run price elasticities of supply will be investigated, using models of dynamic factor demand. Demand functions for capital will be estimated and the factors influencing investment behaviour will be analysed. Annual data from Dutch dairy farms over the period 1970-1982 were used for estimation of the model. The farms usually remain in the panel for about six years; the data set forms an unbalanced panel.

Interesting models of dynamic factor demand can be grouped into three categories. The first category of model is represented by the model used in Chapter 5. In Chapter 5 a fully dynamic model is developed in which capital is quasi-fixed and subject to quadratic adjustment costs. But the approach retains the assumption that producers have static expectations regarding the evolution of input prices. On the other hand, most current rational expectations models, following Sargent's (1978) lead[1], assume that agents themselves both know and use ARIMA type equations in forming expections about the evolution of exogenous variables. A third category of model, represented by the model developed by Pindyck and Rotemberg (1983),

[1] See Pfann (1989) for a very clear description of this method.

relies on a generalized instrumental variables approach to estimate the first order condition. This approach lays much emphasis on the precise theoretical structure of the model but has the great advantage of not requiring models to be specified for the expectations process of prices and fixed inputs. Another feature of this approach is that no intermediate-run price elasticities can be calculated, because the stochastic control problem has not been solved.

In this chapter the first and third strategies are pursued. The second strategy cannot be carried out, because the panel data only contain observations for prices and fixed inputs over a short period.

Starting from an intertemporal profit-maximizing model, the central aim is to model the farmers' formation of expectations about the future path of variables. Two alternative forms are proposed and developed for the purposes of comparison: static expectations and rational expectations. Unlike previous studies, micro data are used.[2] This enables theory formulated in terms of individual decision-making units to be used fruitfully and tested stringently. Instrumental variable methods based on first differences of the variables, were used to estimate the models.

The chapter is organized as follows. In Section 6.2.1 the model based on static expectations is presented. The model based on rational expectations is discussed in Section 6.2.2. The data and estimation methods used are described in Section 6.3. The estimated parameters, elasticities and tests carried out are presented in Section 6.4. Conclusions are presented in Section 6.5.

6.2 The theoretical models

6.2.1 Static expectations

Consider a farm family which maximizes the present value of income over an infinite horizon with respect to two inputs: a variable input (mainly feed) and a quasi-fixed input (livestock, buildings and equipment). In addition to the variable input and the quasi-fixed input two

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[2] Another contrast between the present study and the study done by Morrison (1986), who also compared different expectations specifications, is that the starting point is a discrete-time context. In empirical applications time is a discrete variable; therefore our theoretical model starts from discrete time.

fixed inputs that are not subject to the profit maximization process are distinguished: labour and land.[3] The farm family is a price-taker in the output and variable input markets, a reasonable assumption when using data on Dutch dairy farms.

The farm family's expectations regarding the evolution in prices of inputs and outputs and in the fixed inputs are static: therefore their expectations for the relevant price variables and fixed inputs are fixed at the current level for all future periods. The actual optimal input decisions at time t do not move over time unless actual prices and actual fixed inputs change. The restrictiveness of this assumption may not be as severe as it appears, because farmers adjust their plans (and hence their targets) every year as prices and fixed inputs change. Factor demand for the variable input and the quasi-fixed input for farm h are therefore given by the solution to[4]:

$$\max \ PV_{t,h} = \max \sum_{j=0}^{\infty} \tau^j \left[\pi_{t+j,h} - tc_{t+j,h}\right] \tag{6.1}$$

where PV is present value, τ is a real discount rate ($0 < \tau < 1$), π is the profit function and tc are the total costs of capital. The farm's objective can be viewed as first having to maximize short-run profits (resulting in π) and then to maximize the present value of its long-run profits. Therefore the short-run profit is conditional upon a fixed level of the capital stock.

The short-run profit function represents the production technology for a given capital stock. It was decided to use the quadratic form for empirical analysis. The profit function is normalized by the price of the variable input, to ensure that the profit function is linearly homogenous in prices. The profit function for farm h at time t, is written as:

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[3] The labour input is not very sensitive to price changes; see Chapter 4. Therefore, we assume that labour is exogenous. The changes in amount of land per farm are very sensitive to the availability of land near the farm. No information is available on the latter. Therefore, land is also treated as an exogenous variable.

[4] Models assuming static expectations (see Chapter 5) mostly start from a continuous time context. However, models based on rational expectations start from a discrete time-context. To compare both models, in this study we start from discrete time.

$$\pi_{t,h} = \gamma_0 + (\gamma_{1h} + s_{t,h})k_{t,h} + \tfrac{1}{2}\gamma_2 k_{t,h}^2 + \gamma_3 p_t k_{t,h} + \gamma_4 k_{t,h} n_{t,h} \tag{6.2}$$

where π is the profit normalized by the price of the variable input; p is the ratio of the price of the output to the price of the variable input; k_t is the quasi-fixed input at the beginning of period t; n is a vector with labour, land and technology as variables. Note that the price differs over the years but not over the farms. The random variable s represents random shocks to the marginal revenue of capital. This variable represents (i) measurement errors, (ii) differences between the quadratic functional form and the true underlying function and (iii) optimization errors. We assume that s is a white noise process. In this chapter a demand function for capital is the central element. In the profit function, therefore, only the variables necessary for this demand function are taken into account. The profit function is specified in such a way that the resulting demand function for capital has a constant term that differs over the farms.

If the normalized profit function satisfies certain regularity conditions, it is dual to the production function, and its parameters contain sufficient information to describe the farm's production technology at profit-maximizing points in the set of production possibilities. Because the demand for the quasi-fixed input is the central element in this study the testable regularity conditions are: the normalized profit function increases in the quasi-fixed input and is concave in the quasi-fixed input ($\gamma_2 < 0$).

The farm family faces adjustment costs when it alters its stock of the quasi-fixed input. Changes in this capital stock imply increasing costs arising from integrating new capital into a going concern. Reorganizing the production method is an example of such a cost, as are the learning processes of the farm family members. In line with the literature on dynamic factor demand models (e.g. Nickell (1986)) a quadratic functional form is assumed.[5] Therefore the total costs of capital (tc) are[6]:

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[5] Another possibility is to assume asymmetrical adjustment costs (Pfann, 1989). A disadvantage of the latter approach is that the control problem cannot be solved.

[6] The changes in the capital stock take place at the beginning of the period t. The adjustment costs of this change reduce the income during period t.

$$tc_{t,h} = \tfrac{1}{2}\,\omega\,(k_{t,h} - k_{t-1,h})^2 + c_t k_{t,h} \tag{6.3}$$

where ω is the adjustment cost parameter ($\omega > 0$) and c is the ratio of the costs of the quasi-fixed input (interest costs and depreciation costs[7] corrected for investment subsidies) to the price of the variable input. Adjustment costs imply that input adjustments are sluggish since it is more costly to change stocks quickly than slowly.

The first order conditions necesary for maximizing (6.1), which incorporate (6.2) and (6.3), consist of the Euler equation and a transversality condition which ensure the finiteness of the process (Sargent, 1987). The solution at time t of the Euler equation to this infinite horizon problem satisfying the transversality condition is:

$$\frac{\partial PV_{t,h}}{\partial k_{t,h}} = \frac{\partial \pi_{t,h}}{\partial k_{t,h}} - \omega(k_{t,h} - k_{t-1,h}) - c_t + \omega\tau\,(k_{t+1,h} - k_{t,h}) = 0 \tag{6.4}$$

The Euler equation states that the marginal revenue of capital equals the marginal cost of that capital good. In the absence of adjustment costs ($\omega = 0$) the marginal cost of capital is equal to interest costs plus depreciation costs (c). When adjustment costs are taken into account, the marginal cost of capital have to be corrected for the difference between the adjustment costs of one unit of the capital good at time t and the discounted savings obtained as a result of the adjustment costs of one unit of the capital good at time t + 1.

The Euler equation can also be written as:

$$\begin{aligned} k_{t,h} = {} & \mu^{-1} k_{t+1,h} + \tau^{-1}\mu^{-1}\, k_{t-1,h} + \\ & (\omega\tau)^{-1}\mu^{-1}\,(\gamma_{1h} + \gamma_3 p_t + \gamma_4 n_{t,h} - c_t + s_{t,h}) \end{aligned} \tag{6.5}$$

where $\mu = (\omega\tau)^{-1}(\omega + \omega\tau - \gamma_2)$

According to (6.5), at the beginning of period t the level of the capital good is linearly related to: the level of the capital good at the end of

[7] Differences in depreciation rates for livestock, buildings and equipment are taken into account, see Appendix A.

period t; the capital level lagged by one period; the normalized price of the output during period t; the normalized costs of the capital good during period t; the level of the fixed inputs at the beginning of period t; and the random shock. Assuming static expectations regarding the evolution of prices and fixed inputs, the Euler equation is not the equation that has to be estimated. The level of the capital good at the end of period t, a right-hand side variable, has to be determined in the model. The Euler linear difference model can be solved in a particular way; see Appendix C. The result is:

$$k_{t,h} = \lambda k_{t-1,h} + \lambda \omega^{-1} \sum_{i=0}^{\infty} (\tau\lambda)^i (\gamma_{1h} + \gamma_3 p_{t+i} + \gamma_4 n_{t+i,h} - c_{t+i} + s_{t+i,h}) \qquad (6.6)$$

$$\text{with } \lambda = \tfrac{1}{2}\,\mu - \tfrac{1}{2}\,\sqrt{\mu^2 - 4\,\tau^{-1}}$$

In (6.6) the level of the quasi-fixed input in period t is expressed as a linear relationship between the level of the quasi-fixed factor in the previous period and the future level of all prices and fixed inputs, with the weights forming a geometric progression.

To make this model operational the expectations about the prices and the fixed inputs should be specified. Assuming static expectations, equation (6.6) becomes:

$$k_{t,h} = \lambda k_{t-1,h} + \lambda \omega^{-1} (1 - \tau\lambda)^{-1} \, (\gamma_{1h} + \gamma_3 p_{t-1} + \gamma_4 n_{t-1,h} - c_{t-1} + s_{t,h}) \qquad (6.7)$$

Equation (6.7) is similar to the traditional partial adjustment mechanism.[8] The adjustment rate λ depends on the discount rate τ, on the parameter γ_2 in the profit function and the adjustment cost parameter ω.

Equation (6.7) is rewritten as follows, so it can be used for the estimations:

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[8] Equation (6.7) is not exactly the same as the equation derived by Lucas (1967) and applied by Denny et al. (1981). This is because these authors start from a continuous time context in the theoretical model. An advantage of the approach we use is that it is easy to distinguish more than one capital good, see eg. Sargent (1978). In a model starting from a continuous time context and distinguishing more than one capital good an estimable model can hardly be obtained (see Thijssen, 1989).

$$k_{t,h} = \alpha_{0h} + \alpha_1 k_{t-1,h} + \alpha_2 c_{t-1} + \alpha_3 p_{t-1,h} + \alpha_4 n_{t-1,h} + s_{t,h}$$
$$0 < \alpha_1 < 1 \, , \, \alpha_2 < 0 \tag{6.8}$$

The restrictions on the parameters follow from the assumption that γ_2 is negative, ω is positive and the discount rate τ lies between zero and one. Because of these restrictions λ lies between zero and one (Sargent, 1987:202). Therefore, α_1 lies between zero and one and α_2 should be less than zero. There are no theoretical restrictions to α_3 and α_4.

6.2.2 Rational expectations

Consider a farm family which maximizes the expected present value of income over an infinite horizon with respect to two inputs in an uncertain environment. The two inputs are a variable input and a quasi-fixed input. Two fixed inputs that are not subject to the profit maximization process are also distinguished: labour and land.

The farm family uses all relevant information up to time t, including the prices of inputs and output and the levels of the fixed inputs, to choose contingency plans for the variable input and the quasi-fixed input. In order to determine the actual optimal input decisions at time t, the rational farmer has to plan future input decisions. He will revise his plans at time t+1 in the light of new information. Factor demand for the variable input and the quasi-fixed input for farm h at time t are therefore given by the solution to:

$$\max PV_{t,h} = \max E_t \sum_{j=0}^{\infty} \tau^j \, [\, \pi_{t+j,h} - tc_{t+j,h} \,] \tag{6.9}$$

the operator E_t is defined as the conditional expectations $E_t \, y \equiv E(y|\Omega_t)$, where y is a random variable and Ω_t is the set of information available to the farmer at the beginning of period t.

For empirical analysis, and to compare both models, it was decided to use the quadratic forms for the profit function and the adjustment cost function; see equations (6.2) and (6.3). The first order condition necessary for maximizing (6.9) consists of the Euler equation:

$$k_{t,h} = \mu^{-1}E_tk_{t+1,h} + \tau^{-1}\mu^{-1}\ k_{t-1,h} + (\omega\tau)^{-1}\mu^{-1}(\gamma_{1h} + \gamma_3E_tp_t + \gamma_4n_{t,t} - E_tc_t + s_{t,h}) \tag{6.10}$$

where $\mu = (\omega\tau)^{-1}(\omega + \omega\tau - \gamma_2)$

Equation (6.10) is similar to equation (6.5) except for the conditional expectations. According to (6.10), at the beginning of time t, the level of the capital good is linearly related to: the expected level of the capital good at the end of period t; the capital level lagged by one period; the expected normalized price of the output during period t; the expected normalized costs of the capital good during period t; the level of the fixed inputs at the beginning of period t; the random shock.

Using the rational expectations hypothesis, the expectation of the quasi-fixed input and the prices in equation (6.10) can be removed by adding a forecasting error term $e_{t+1,h}$ ($= k_{t+1,h} - E_tk_{t+1,h} + p_t - E_tp_t + c_t - E_tc_t$) to this equation. This forecasting error term does not correlate with lagged variables or s_t, it is orthogonal to the information set Ω_t. The resulting equation can be rewritten as:

$$k_{t,h} = \beta_{0h} + \beta_1k_{t+1,h} + \beta_2k_{t-1,h} + \beta_3c_t + \beta_4p_t + \beta_5n_{th} + s_{t,h} + e_{t+1,h} \qquad 0 < \beta_1 < \beta_2 < 0.5,\ \beta_3 < 0 \tag{6.11}$$

The restrictions on the parameters follow from the assumption that γ_2 is negative, ω is positive and the discount rate τ is almost one.[9] There are no theoretical restrictions to β_4 and β_5.

The Euler equation approach has an important advantage: it depends solely on variables observed in the sample period. Contrast this with the approach where the Euler equation has been solved, see e.g. Kodde et al. (1990). The latter approach results in an equation similar to equation (6.6), which requires out of sample predictions to be derived from a model that predicts future values of the prices and the fixed inputs.

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[9] The restrictions on the parameters can easily be derived, for example $\beta_1 < 0.5$ because $\mu = (\omega\tau)^{-1}(\omega + \omega\tau - \gamma_2) = 1 + \tau^{-1} - \gamma_2(\omega\tau)^{-1} > 2$, given that $\tau < 1$ and $\gamma_2 < 0$ and $\omega > 0$.

This approach assumes that farmers themselves both know and use this model, mostly based on time-series analysis, to predict future values of prices and fixed inputs.[10]

Another advantage of the Euler equation approach is that it yields more restrictions on the parameters than in the static expectations model, which can be tested empirically.

If no additional assumptions are made about the future path of prices and the fixed inputs, the stochastic control problem cannot be solved. This is a disadvantage of the Euler equation approach; it means that no optimal factor-demand trajectories corresponding to particular stochastic processes for prices can be calculated (Pindyck and Rotemberg, 1983).

6.3 Data and estimation

The data used in this study are from a sample of Dutch farms that kept accounts of their farming for the Agricultural Economics Research Institute. Annual data from dairy farms for the period 1970-1982 were used for estimation of the model. The farms usually remain in the panel for about six years, the data set forms an unbalanced panel. The sample used comprised 178 farms for which at least 5 consecutive years of observations were available, see Table 6.1.[11]

Four inputs were included in the profit function: labour in hours (family and hired labour), capital (livestock, buildings and machinery), land in hectares, and a normalized price (the ratio of the Törnqvist price index of the output to the Törnqvist price index of the variable input). An implicit quantity index for the capital good was obtained as the ratio of the value to the Törnqvist price index. The Törnqvist price index used was the annual average of the price indices of the different farms. The

[10] In the approach used by Kodde et. al. the demand function for capital is estimated as well as price equations and equations for the fixed inputs. We did not do this in our study, because the panel data only contain observations for prices and fixed inputs over a short period. Moreover, the computer program we use can only be applied to a single equation.

[11] The computer program used to estimate the model only works if some farms have observations for all of the years covered by the data set. However, in the data set used, none of the farms had data for each of the years 1970-1982. Six similar farms were therefore pooled to yield three farms that have observations for all of the years.

prices of machinery and building capital were corrected for investment subsidies. The costs of capital are composed of interest costs and depreciation costs, see Appendix A. Values of the volume of capital at the beginning and end of the period were used. For a complete description of the data, see Section 1.3 and Appendix A.

Table 6.1 Numbers of farms and observations

Number of years per farm	Number of farms	Number of observations
5	81	405
6	72	432
7	21	147
8	1	8
13	3	39
Total	178	1031

The demand equation for capital based on static expectations, developed in Section 6.2.1, contains firm-specific effects. The equation for farm h at year t+1 has the form:

$$k_{t+1,h} = \alpha_{0h} + \alpha x_{t,h} + \zeta_{t+1,h} \qquad h = 1...H,\ t = 1...T_h \tag{6.12}$$

where k_{t+1} is the capital stock at the end of the period t; x is a vector of explanatory variables: prices during period t, fixed inputs and the capital stock at the beginning of period t; α_{0h} is the specific effect (fixed or random) of farm h representing the effects of those variables peculiar to the hth individual in more or less the same fashion over time; α is a vector of parameters; T_h is the number of years of records available on farm h; the first year of estimation is 1972; and ζ is the error term. We assume that $\zeta_{t+1,h}$ can be characterized by an independently identically distributed random variable with mean zero, but arbitrary forms of heteroskedasticity across farms and time are possible.

If the farm-specific effects are fixed, the fixed effects estimator is no longer consistent in the typical situation in which a panel involves a large number of individuals, but over only a short period of time. If the farm specific effects can be treated as random, the consistency of the maximum likelihood estimator and the interpretation of the model depend on the assumption about the initial observations (Hsiao, 1986). An important assumption that must be made for the random effects estimator to be consistent is that the individual effect and the regressors are independent. Doubts have been raised about this assumption in a static model, see Chapter 3. Instrumental variable methods were used to obtain an estimator that overcomes these problems.

To eliminate α_{0h} we take the first differences of equation (6.12). The resulting equation is as follows for farm h (in matrix notation):

$$k_h^* = \alpha X_h^* + \zeta_h^* \qquad (6.13)$$

where k_h^*, X_h^* and ζ_h^* denote first differences of k_h, X_h and ζ_h. Because $k_{t,h}$ (which is an element of $x_{t,h}$) is correlated with $\zeta_{t,h}$ an instrumental variable method must be used to obtain a consistent estimator. Taking into account that first differencing induces MA(1) serial correlation, a generalised method of moments (GMM) estimator was used (Arellano and Bond, 1988b):

$$\hat{\alpha} = [(\Sigma_h X_h^{*\prime} Z_h)\, A_H\, (\Sigma_h Z_h' X_h^*)]^{-1} (\Sigma_h X_h^{*\prime} Z_h)\, A_H\, (\Sigma_h Z_h' k_h^*) \qquad (6.14)$$

where $A_H = (1/H\ \Sigma_h Z_h' W_h\ Z_h)^{-1}$ and Z_h is a matrix of instruments. The structure of this matrix is complicated. For example, for a farm which is in the sample for the period 1970 - 1975 the matrix for the capital stock is given by:

$$Z = \begin{bmatrix} k_{1970} & k_{1971} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & k_{1970} & k_{1971} & k_{1972} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & k_{1971} & k_{1972} & k_{1973} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & k_{1972} & k_{1973} & k_{1974} \end{bmatrix}$$

Note that the first year of estimation is 1972.[12] So the first difference of the capital stock at the beginning of the year (right-hand side variable in equation (6.13)) is equal to k_{1972} - k_{1971}. k_{1971} is a valid instrument for this variable because it does not correlate with the corresponding error term ζ_{1973} - ζ_{1972}. Of course, k_{1970} is also a valid instrument. For the years 1973 up to 1975 three levels of the capital stock are used as instruments. Other instruments used are the first differences of the price ratios, the labour volume and the amount of land; the age of the farmer; and the farm size lagged by one period.

The weighting matrix $W_h = \hat{\zeta}_h^{*\prime}\hat{\zeta}_h^{*}$, where $\hat{\zeta}_h^{*}$ are residuals of a one-step estimator of α based on a matrix W with elements:

$$w_{tr} = \begin{cases} 2 & \text{for } t=r \\ -1 & \text{for } |t-r|=1 \\ 0 & \text{otherwise} \end{cases}$$

The two-step estimator is more efficient than the one-step estimator, when ζ_{th} is heteroscedastic (Arellano and Bond,1988a).

The demand function for capital based on rational expectations, developed in Section 6.2.2, also contains firm specific effects:

$$k_{t,h} = \beta_{0h} + \beta y_{t+1,h} + \xi_{t,h} \qquad h=1...H,\ t=1...T_h \tag{6.15}$$

with $\xi_{t,h} = s_{t,h} + e_{t+1,h}$

[12] The first year of estimation in the rational expectations model is 1972. To compare the results of both models we start in the same year for both models.

where k_t is the capital stock at the beginning of period t; y_{t+1} is a vector of explanatory variables: the capital stock at the end of period t, prices during period t, fixed inputs at the beginning of period t and the capital stock at the beginning of period t-1; β_{0h} is the specific fixed effect of farm h representing the effects of those variables peculiar to the hth individual in more or less the same fashion over time; β is a vector of parameters; ξ is the error term. To eliminate β_{0h} equation (6.15) was also transformed to a first difference equation. Taking into account that the error term of the first difference of equation (6.15) is generated by an MA(1) process, the following GMM estimator is an efficient estimator[13] (Nijman, 1990: 519-523):

$$\hat{\beta} = [\ (\Sigma_h Y_h^{*\prime} Z_h)\ A_H\ (\Sigma h Z_h{}' Y_h^{*})\ ]^{-1}\ (\Sigma_h Y_h^{*\prime} Z_h)\ A_H\ (\Sigma_h Z_h{}' k_h^{*}) \qquad (6.16)$$

The matrix A_H has the same form as in equation (6.14). The Z matrix differs from the static expectations model. For a farm which is in the sample for the period 1970 - 1975 the matrix for the capital stock is given by:

$$Z = \begin{bmatrix} k_{1970} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & k_{1970} & k_{1971} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & k_{1970} & k_{1971} & k_{1972} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & k_{1971} & k_{1972} & k_{1973} \end{bmatrix}$$

Note that the first year of estimation is 1972, because otherwise there is no capital stock as instrument available for the first year. k_{1971} is not a valid instrument in the first year of estimation, because k_{1971} is correlated with the corresponding error term $\xi_{1972} - \xi_{1971} = s_{1972} - s_{1971} + e_{1973} - e_{1972}$. Other instruments used are the price ratios, the volume

[13] The first difference of ξ is $u_t = s_t + e_{t+1} - (s_{t-1} + e_t)$. u_t is generated by a MA(1) process:

$Eu_tu_{t-k} = Es_ts_{t-k} + Es_te_{t+1-k} - Es_ts_{t-1-k} - Es_te_{t-k} + Ee_{t+1}s_{t-k} + Ee_{t+1}e_{t+1-k} - Ee_{t+1}s_{t-1-k} - Ee_{t+1}e_{t-k} - Es_{t-1}s_{t-k} - Es_{t-1}e_{t+1-k} + Es_{t-1}s_{t-1-k} + Es_{t-1}e_{t-k} - Ee_ts_{t-k} - Ee_te_{t+1-k} + Ee_ts_{t-1-k} + Ee_te_{t-k}$.

If $k > 2$ all terms cancel out because s is assumed to be a white noise process and the properties of the forecasting error term. If $k=1$ then $Eu_tu_{t-1} = Es_te_t - Es_{t-1}s_{t-1} + Es_{t-1}e_{t-1}$.

of labour and the amount of land, all lagged by one and two periods; the age of the farmer; and the farm size lagged by two periods. Unlike the static expectations model the current levels of prices correlate with the error term $\xi_{t,h}$.

The assumption of no second-order serial correlation of the error terms is essential for the consistency of the estimators, in view of the instruments used. Tests of first order and second order serial correlation were carried out for the two models. These tests are based on the standardised residual autocovariances which are asymptotically N(0,1) distributed under the null hypothesis of no autocorrelation (Arellano and Bond, 1988a).

The Sargan test was also applied. In the instrumental variable estimation d_1 linear combinations of the d_2 orthogonality conditions are set to zero, where d_1 is the number of unknown parameters and d_2 is the number of instruments. Because d_2 is larger than d_1, there are d_2 - d_1 remaining linearly independent orthogonality conditions that are not set to zero in estimation, but which should be close to zero if the model restrictions are true. To test these overidentifying restrictions, a statistic that is asymptotically distributed as a chi-square with d_2 - d_1 degrees of freedom under the null hypothesis of the validity of the instruments, was calculated (Hansen and Singleton, 1982).

The models were estimated using a special program for dynamic panel data estimation developed by Arellano and Bond (1988b).

6.4 Results

The estimated coefficients of the two models are presented in Table 6.2. There were 178 farms and 1031 observations used for estimation of the model. The first two years of observations from every farm were used as instruments (see Section 6.3).

The Wald test reported is a test of the null hypothesis that the estimated coefficients for all the variables in the model are equal to zero. The Wald tests are asymptotically distributed as χ^2 variables, with the degrees of freedom as indicated. According to the Wald tests reported, there is a joint significance of the variables for both models. The parameters of capital stocks and prices are significant in both models. The fixed inputs labour and land are not very significant.

Table 6.2 Parameter estimates of the factor demand equation for two ways of specifying expectations (standard errors in parentheses)

Variable	Static expectations	Rational expectations
$Capital_{t+1}$		0.48 (0.05)
$Capital_{t}$	0.71 (0.06)	
$Capital_{t-1}$		0.39 (0.03)
Capital $costs_{t}$[1]	-927.62 (420.95)	1020.83 (419.99)
Price $output_{t}$[1]	69.97 (34.72)	-77.45 (23.04)
$Labour_{t}$	0.01 (0.01)	-0.01 (0.01)
$Land_{t}$	0.79 (0.72)	1.43 (1.66)
Technology	5.1 (1.82)	-0.4 (1.57)
Wald test[2]	219.93 (5)	632.8 (6)
Sargan test[2]	52.31 (33)	48.67 (34)
Test on serial correlation[3]		
- first order	-3.36 (178)	-4.39 (178)
- second order	-1.63 (178)	1.07 (178)

[1] Normalized by the price of the variable input

[2] Degrees of freedom in parentheses

[3] Number of farms used in parentheses

Farms that have been in the sample for thirteen years have 39 instruments: ten years with three lagged values of the capital stock; one year with two lagged values of the capital stock (see equation (6.15)); six exogenous variables; and the constant term. For farms which have been in the sample for less than thirteen years, the matrix of instruments contains columns of zeros because observations of the capital stock are incomplete. For 33 (39 instruments minus 6 parameters) degrees of freedom and a 1 percent significance level, the critical χ^2 value is 54.77.[14] Therefore, the null hypothesis that the overidentifying restrictions hold cannot be rejected.

The other tests carried out were on serial correlation. The reported values are asymptotically N(0,1) distributed. In Table 6.2 the numbers of farms used to calculate these values are given in parenthesis. All the farms were used to calculate these values, because each farm was in the sample for at least five years. This is the minimum period required to be able to calculate the test statistic for the second order serial correlation (Arellano and Bond, 1988a). These tests show that the null hypothesis of no first order correlation of the error term can be rejected for both models: this is as expected for a model using first differences. Absence of second order serial correlation cannot be rejected for both models. Absence of second order correlation of the error terms is essential for the consistency of the estimators such as those considered in Section 6.3.

According to the theory developed in Section 6.2 there are restrictions on the parameters of the models. For the static model the coefficient for capital is less than one and the coefficient for the capital costs is negative. The structural parameters of the model are identified, if a value for the real discount rate is assumed. The real discount rate was chosen to be 0.98. The parameter of the quadratic term of the capital volume in the profit function γ_2 turns out to be -0.0003. Therefore the profit function is concave in capital. The adjustment cost parameter equals 0.0025; the adjustment costs are approximately 4% of the total costs of capital (this is similar to the result of Chapter 5, see p.77). Therefore, the basic assumptions underlying the methodology of this model, that farmers are profit maximizers and have static expectations, are not rejected by the data.

It is not unexpected for Dutch farmers to have static expectations about the evolution of prices over time. The Dutch farming sector is greatly influenced by EC policies. For the dairy sector this results in stable prices for milk and beef.

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[14] If the sample is large it is more appropriate to choose a small significance level (Leamer 1978, Chapter 4).

The results obtained for the rational expectations model are not consistent with the theory.[15] The parameter of the capital stock at the end of the period is greater than the parameter of the capital stock at the beginning of the previous year and the parameter of the capital costs is positive. The structural parameters of the model turn out to be 1.18 for the real discount rate (but should be less than one), -0.0004 for the adjustment parameter (but should be positive) and 0.0001 for the parameter of the quadratic term of the capital volume in the profit function (but should be negative).

The reasons that the model based on rational expectations is rejected can be: misspecification of the model; there may have been optimization errors; the farmers may have had non-rational expectations. Pindyck and Rotemberg (1983:1072) have also questioned the validity of the rational expectations model. Using the Sargan test described in Section 6.3 they rejected the null hypothesis that the overidentifying restrictions are close to zero. They attributed the failure of their model to either a misspecification of the model, or to absence of optimization with rational expectations on the part of firms.

These results raise doubts about the assumption that the farmers' expectations about the quasi-fixed input and the prices are equal to these variables plus a forecasting error term that does not correlate with lagged variables. Therefore, the elasticities of the demand for capital are calculated only for the model based on static expectations, see Table 6.3. However, note that the rational expectations model relies more heavily on the underlying model than the static expectations model (compare the restrictions on the parameters of equation (6.8) and equation (6.11)). Therefore, it is easier to reject the rational expectations model than the model based on static expectations.

As can be concluded from Table 6.3, the demand for capital is sensitive to changes in the price of the output and capital costs. The elasticity of the price of the variable input (mainly feed) is negative. Variable input and capital stock, are complements, as labour and capital, and land and capital. This is a plausible outcome for the Dutch dairy sector. However, the elasticities are small, even in the long-run. This is probably caused by counteracting elements between these factors. For example, an increase in family labour can allow herd size to

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[15] And the results for the rational expectations model are still not consistent with the theory even after a restriction has been imposed on the discount rate (τ = 0.98).

increase, but it can also replace machinery. The influence of technical change on the demand for capital is very important.

Table 6.3 Estimated elasticities of the demand for capital, using the model based on static expectations, at the sample mean (standard errors in parentheses)

Variable	Short-run (one year)	Intermediate-run (three years)	Long-run (ten years)
Output price	0.17 (0.08)	0.38 (0.11)	0.59 (0.27)
Capital costs	-0.13 (0.06)	-0.29 (0.07)	-0.45 (0.20)
Variable input price	-0.04 (0.01)	-0.09 (0.01)	-0.13 (0.04)
Labour	0.06 (0.05)	0.13 (0.05)	0.21 (0.17)
Land	0.04 (0.04)	0.09 (0.05)	0.13 (0.14)
Technical change	0.012 (0.004)	0.027 (0.005)	0.041 (0.014)

The gross investments in the capital stock equal 10% of the capital stock. Therefore, the short-run elasticities of the investments are ten times the elasticities of the capital stock. Investments are sensitive to: changes in the price of the output; capital costs; and technical change. Investment subsidies are, therefore, useful incentives if the investments have to be stimulated.

The estimated parameters of the model based on static expectations were also used to calculate own price elasticities of output supply. The study of Chapter 3 about the short-run response of Dutch farms in terms of supply was used for this. The results were: a short-run price elasticity of the output equal to 0.10, and an elasticity of output with respect to capital equal to 0.37 (see Table 3.2, p.44). Combining these results with the results of Table 6.3 gives a price elasticity of the output of 0.23 for the intermediate-run and 0.32 for the long-run. Despite the large price elasticity of investments the difference between the short-run price elasticity and the long-run price elasticity of the output is not very large. This is caused by:

- the relatively small coefficient for capital (0.71) in the estimated equation, see Table 6.2. In models where no fixed effects are taken into account, this coefficient is almost one. Therefore, the differences between the short-run and the long-run price elasticities of the capital stock with respect to the prices are not very large, see Table 6.3.
- investments are very sensitive to a change in the price of the output. However, the elasticity of the capital stock is only 0.59 over a period of ten years.
- the elasticity of output supply with respect to capital is only 0.37.

The elasticities are comparable with the results of Chapter 5 (Tables 5.2 and 5.3). There are some differences between the elasticities of the two chapters. This is caused by several factors

- different models: Chapters 5 and 6 start from an intertemporal profit-maximizing model and adjustment costs, but Chapter 5 starts from a continuous time context and many cross-equation restrictions on the parameters were introduced. This chapter starts from a discrete time context. The short-run normalized profit function is normalized by the price of the output (Chapter 5) and by the price of the variable input (this chapter).
- different estimation techniques: in this chapter it was possible to take into account of a special set of instruments and to take account of the specific structure of the error terms.
- differences in the sample: in this chapter the sample used comprised only farms for which at least 5 consecutive years of observations were available.

6.5 Conclusions

Starting from neoclassical theory and two possible types of expectation about the future path of variables, the demand functions for capital were estimated using data from an incomplete panel of dairy farms. The main conclusions of the study are

(a) The model based on static expectations seems to provide an appropriate description of the decisions made by dairy farmers in the Netherlands about the demand for capital, because its underlying assumptions are not rejected by the data and the elasticity estimates are reasonable.

(b) The results obtained using the model based on rational expectations are not consistent with the theory. The assumption of rational expectations among Dutch dairy farmers is questionable.

(c) Because panel data are available, one may allow for the possibility that the intercept in the demand function for capital varies over the farms. The fixed effects estimator is, however, not consistent for dynamic models. Therefore an instrumental variable estimator was used, based on first differences of the variables.

(d) Investments are very sensitive to changes in the price of the output, changes in capital costs and technical change. Price policy is, therefore, a useful instrument to influence investment behaviour. Changes in the amount of labour and land do not have a great effect on the investment behaviour of farmers.

(e) The own-price elasticity of the output is 0.10 in the short-run, 0.23 in the intermediate-run and 0.32 in the long-run for the model based on static expectations for the prices and the fixed factors. The potential of traditional agricultural policies and of environmental policies to influence the level of supply by means of levies or subsidies is therefore limited in the long-run.

CHAPTER 7

CONCLUSIONS

7.1 The models

In this study, empirical micro-economic models of the production behaviour of farm households were estimated using an incomplete panel of Dutch dairy farms. The models fit the data well, because the restrictions implied by neoclassical production theory are not rejected by the data and the elasticity estimates are reasonable. Many assumptions were made to derive these quantitative models. The main conclusions about these assumptions are

(a) When as in Chapter 2, a flexible functional form is used to describe the production technology, the primal and dual approaches are not significantly different.

(b) The fixed effects estimator is preferable to the random effects estimator for estimating short-run input demand and short-run output supply. The intercepts of these equations are not the same for all farms and reflect mainly differences in management and in the quality of land (see Chapter 3).

(c) Introducing labour as a variable input into the model does not have a large impact on the price elasticities of the output supply and the demand for the variable input (row 1 and 2 of Table 7.1), because the values of the elasticity of labour in the output supply equation and the endogenous wage elasticity of labour supply turn out to be small (see Chapter 4).

(d) The hypothesis of instantaneous capital adjustment to changing prices is statistically rejected. Capital adjustment costs play a substantial role in determining short-run and intermediate-run behavioural responses. The adjustment rate to the optimal level is equal to 26% per year (see Chapter 5).

(e) The model based on rational expectations had to be rejected because the model may have been misspecified, there may have been optimization errors, and/or the farmers may have had non-rational expectations. The model based on static expectations fits the data well. (see Chapter 6)

(f) Short-run profit maximizing behaviour is an indispensable assumption in the models distinguished. In Chapter 4 utility maximizing behaviour is assumed, in Chapters 5 and 6 the present value of income over an infinite horizon is maximized. However, in all these models short-run profit maximizing behaviour is implicitly assumed.

(g) In Chapter 5 a dynamic model, starting from a continuous time context, was estimated. In Chapter 6 a demand function for a quasi-fixed input, based on static expectations and starting from a discrete time context, was estimated. The advantage of the approach used in Chapter 5 is that cross-equation restrictions on the parameters of the short-run profit function, the short-run demand function for the variable inputs and the demand function for the quasi-fixed input can be taken into account. The advantage of the approach used in Chapter 6 is that more than one quasi-fixed input can be taken into account.

(h) In Chapters 3 to 6 a quadratic functional form was assumed for the short-run normalized profit function. This functional form is also flexible, but in contrast to the translog form (used in Chapter 2) it is self-dual. The advantages of the quadratic functional form are that theoretical restrictions can be tested globally and that explicit forms can be obtained for: (i) the demand function for the variable input and the supply function for the output (Chapter 3), (ii) the marginal income of labour (Chapter 4), and (iii) the demand function for capital (Chapter 5 and 6). A disadvantage of the quadratic short-run normalized profit function is that the results can be sensitive to the way the function is normalized, by the price of the output (Chapter 5) or by the price of the variable input (Chapter 6).

The empirical micro-economic models turn out to be useful devices for analysing the assumptions made.

7.2 Elasticities of the Dutch dairy farms

The micro-economic models were estimated using annual data from Dutch dairy farms over the period 1970-1982. Table 7.1 gives an overview of the output price elasticities calculated in the various chapters. As a result of the homogeneity restriction, the short-run elasticities for the price of the variable input are the opposite of the output price elasticities. Table 7.2 gives the elasticities of the output supply for capital, land, labour, and technical change. All elasticities are related to the average farm in the sample, i.e. the averages for all variables were calculated using the sample of farms.

There are some differences between the elasticities of the different chapters. This is caused by several factors:

- different models: Chapters 2 and 3 start from short-run profit maximizing behaviour; Chapter 4 starts from utility maximizing behaviour; Chapter 5 and 6 start from an intertemporal profit-maximizing model and adjustment costs, but Chapter 5 starts from a continuous time context and many cross-equation restrictions on the parameters were introduced. Chapter 6 starts from a discrete time context. The short-run normalized profit function is normalized by the price of the output (Chapters 3 to 5) and by the price of the variable input (Chapter 6).
- different estimation techniques: (i) in Chapters 2 and 3 a fixed effects estimator was used that is more efficient than the first differences estimator of Chapters 5 and 6; (ii) a special program for dynamic panel data estimation could be used in Chapter 6.
- differences in the sample: in Chapters 5 and 6 there are fewer observations than in Chapters 2, 3 and 4 because in Chapters 5 and 6 first differences of the variables were used. In Chapter 6 the sample used comprised only farms for which at least 5 consecutive years of observations were available.

The main conclusions with respect to the estimated elasticities are

(a) Price elasticities of the supply of the output and the demand for the variable input turn out to be very small in the short-run (see Table 7.1).

(b) The short-run elasticities of output supply for the amount of capital and land are not small (see Table 7.2). The elasticities of the (quasi-) fixed inputs and technical change in the short-run output supply equation were divided into two effects: (i) a direct effect, by way of the production function (see Chapter 2); (ii) an indirect effect by way of the demand function for the variable input (see Chapter 3). The effect of land on the output supply reflects the scarcity of land in the Dutch dairy sector. In contrast, the effect of capital on the output supply is mainly caused by the positive influence of capital on the demand for the variable input; the variable input and capital are complements. The influence of technical change in the production function is only 0.6% per year in the short-run, the total effect of technical change in the output supply function is about 2.3% in the short-run (see Table 7.2). This is caused by technical change greatly influencing the demand for the variable input.

Table 7.1 Output price elasticities of output supply, variable input demand, labour supply, and the demand for capital; in the short-run (SR) and the long-run (LR), at the sample mean, standard errors in parentheses (- indicates that the elasticity is not available)

Chapter	Output supply		Variable input demand		Labour supply		Capital demand	
	SR	LR	SR	LR	SR	LR	SR	LR
Ch.3	0.10 (0.03)	-	0.25 (0.07)	-	0[1]	-	0[1]	-
Ch.4[2]	0.13	-	0.25	-	0.22	-	0[1]	-
Ch.5	0.01 (0.02)	0.27 (0.07)	0.03 (0.06)	0.33 (0.09)	0[1]	0[1]	0.15 (0.04)	0.52 (0.11)
Ch.6	0.10[3] (0.03)	0.32 (0.10)	0.25[3] (0.07)	0.52 (0.14)	0[1]	0[1]	0.17 (0.08)	0.59 (0.27)

[1] The input is a fixed input
[2] Standard deviations are not available
[3] Obtained from Chapter 3

Table 7.2 Elasticities of the output supply for capital, land, labour, the first derivative for technical change; in the short-run (SR) and the long-run (LR), at the sample mean, standard errors in parentheses (- indicates that the elasticity is not available)

Chapter	Capital	Land		Labour		Technical change	
	SR[1]	SR	LR	SR	LR	SR	LR
Ch. 2[2]	0.36 (0.02)	0.44 (0.04)	-	0.17 (0.04)	-	0.021 (0.003)	-
Ch. 3	0.37 (0.01)	0.43 (0.03)	-	0.17 (0.03)	-	0.023 (0.001)	-
Ch. 5	0.50 (0.07)	0.24 (0.04)	0.46 (0.07)	0.14 (0.03)	0.15 (0.06)	0.025 (0.005)	0.061 (0.008)
Ch. 6	0.37[3] (0.01)	0.43[3] 0.03)	0.48[4] 0.06)	0.17[3] (0.03)	0.25[4] (0.07)	0.023[3] (0.001)	0.038[4] (0.005)

[1] The LR elasticity is irrelevant, because capital is variable in the long-run
[2] See Table 3.3
[3] Obtained from Chapter 3
[4] Combining the results of Chapter 3 and Table 6.3

(c) The demand for capital is sensitive to changes in the price of the output, capital costs, and technical change. The elasticity of the demand for capital for the price of the variable input is negative. Labour and capital are complementary, as are land and capital. The gross investments in the capital stock equal 10% of the capital stock. Therefore, the short-run elasticities of investment are the short-run elasticities of the demand for capital, multiplied by ten. The investments are very sensitive to: changes in the price of the output (see Table 7.1); capital costs; and technical change. Investment subsidies are, therefore, useful incentives if the investments have to be stimulated.

(d) Factors determining the demand for the variable input and the supply of the output in the intermediate- and long-run are the amount of land and technical change; changes in the amount of labour do not have a great effect (see Table 7.2). If capital is fully adjusted to the optimal level, the variable input and the output growth rate is about 5% per year, solely because of technical change.

(e) The price elasticities of the output and the variable input are very small in the short-run, but remain small in the intermediate-run and even in the long-run (see Table 7.1). This is caused by: the elasticities of output supply and variable input demand with respect to capital are not very large (see Table 7.2); the relatively high adjustment rate in the estimated demand function for capital, which means that the differences between the short-run and the long-run price elasticities of the capital stock with respect to the prices are not very large (see Table 7.1); and the price elasticities of the capital stock are very small in spite of investments that are very sensitive to prices changes in the short-run (see Table 7.1). The potential of agricultural price policies and of environmental policies to influence the level of output supply and variable input demand by means of levies or subsidies is therefore limited, even in the long-run.

7.3 Discussion

In Chapters 2 through 6, emphasis is placed on different specific micro-economic aspects of the production behaviour of farmers. The empirical micro-economic models turn out to be useful devices for analysing the determinants of agricultural production, because the models seem to provide an appropriate description of the input and output decisions of dairy farmers in the Netherlands. The assumptions underlying the models are not rejected by the data and the elasticity estimates are reasonable. However, comparing these results with results from other studies indicate that the estimates of the output price elasticities are small, with the exception of the short-run output price elasticity obtained by Elhorst (1990). This may because most of the studies in literature use aggregate data (e.g. Oskam and Osinga, 1982; Roemen, 1990). At an aggregate level it is plausible for price elasticities to be larger, because of (i) changes in the number and size of farms if prices change, (ii) the larger price elasticities of mixed farms, and (iii) changes in the distribution of farms if prices change.

In future research we aim to take into account

(a) external effects (EIT, 1992); dairy farms produce desirable outputs (milk and meat) but also undesirable ones that affect the environment (surplus of manure). The latter will be taken into account into the profit function and shadow prices will be calculated. These shadow prices can be used to analyse the effects of taxes on production of undesirable outputs;

(b) quota system (Helming et al., 1992); in 1984 the superlevy system was introduced in the EC. Therefore a restricted profit function, with milk quotas as a quasi-fixed output will be analysed;

(c) dynamic models based on utility maximizing behaviour; in Chapters 5 and 6 dynamic models were developed with labour as a fixed input and investments financed at a constant discount rate. This model should be extended to take into account changes of labour and the savings used by the family farm to finance the investments;

(d) groups of farms; in this thesis only elasticities are calculated for the average farm. With micro-economic models it is possible to calculate elasticities for different groups of farms;

(e) sector level; elasticities at the farm level can be calculated using micro-economic models. To generate effects at the aggregate level the number, size and distribution of farms have to be taken into account.

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A P P E N D I X   A

THE DATA

The data used in this study are from a sample of Dutch farms that kept accounts of their farming for the Agricultural Economics Research Institute. Annual data from dairy farms for the period 1970-1982 were used for estimation of the model. The farms usually remain in the panel for about five years, the data set forms an unbalanced panel. The sample used comprised 720 farms and 2348 observations.

Table A.1 Numbers of farms and observations

Number of records on each farm	Number of farms	Number of observations
1	153	153
2	137	274
3	124	372
4	111	444
5	91	455
6	79	474
7	24	168
8	1	8
Total	720	2348

When a fixed effects estimator is used, only farms can be taken into account for which at least 2 observations are available. Therefore the number of farms in the sample used in the Chapters 2, 3, and 4 is equal to 720 - 153 = 567. The number of observations is 2348 - 153 = 2195.

In Chapter 5 a first differences estimator is used. The number of observations is 2348 - 720 (the number of farms) - 54 (the number of observations which are not consecutive) = 1574. The number of farms in the sample used is equal to 554 (= 720 - (153 + 13) (the number of farms which have not at least two consecutive years of observations available)).

In Chapter 6 six similar farms were pooled to yield three farms that have observations for all of the years. The number of years that these farms are in the sample is 6 and 7, respectively. The number of farms used is given in Table 6.1. Only farms were used for which at least 5 consecutive years of observations are available. Therefore the number of farms for which at least 5 and 6 years are available is less than the number of farms given in Table A.1.

Figures of the average farm per year are presented in Table 1.3. Implicit quantity indices for the output, the variable input and capital were obtained as the ratios of the value to the Törnqvist price index. The Törnqvist price index for the variable input (the same hold for capital and the output), which is composed of k components, of farm h takes the following form:

$$\log P_{th} = \sum_{i=1}^{k} \tfrac{1}{2} \, (s_{ith} + s_{i80}) * (\log p_{ith} - \log p_{i80}) \tag{A.1}$$

where:

P_{th} = Törnqvist price index for the input in year t on farm h
s_{ith} = share of component i on farm h in year t
s_{i80} = average share of component i in the input at 1980
p_{ith} = price index of component i for farm h in year t
p_{i80} = average price of component i at 1980

The price index used per farm is not the index of equation (A.1) but the average of this index over the farms for one year. Table A.2 gives an overview of the prices indices and capital costs used in this study. The prices of components of the output and the variable input which could not be calculated from the sample were obtained from LEI/CBS, Landbouwcijfers.

The prices of the components of capital were calculated from the sample. Values of the volume of capital at the beginning and end of the period per farm were used (Elhorst, 1986:82)

$$\Delta p_{kt} = (cb_t - ce_{t-1})/ce_{t-1} \tag{A.2}$$

where:

Δp_{kt} = change in the price of capital k in year t
cb_t = value of the volume of capital at the beginning of year t
ce_{t-1} = value of the volume of capital at the end of year t-1

These price changes for livestock, buildings and machinery were combined using a Törnqvist price index, like equation (A.1). The advantage of using equation (A.2) is that revaluation of capital goods by the Agricultural Economic Institute are taken into account. The capital costs are not calculated on the basis of these price changes, but are obtained using price indices of capital foods from LEI/CBS, Landbouwcijfers.

We assume that the investment price of an asset equals the present value of its future capital costs. Assuming that the capital costs are constant over time and discarding taxes:

$$p_k = \sum_{j=1}^{n} c \;/\; (1 + r)^j \qquad \text{(A.3)}$$

where:
p_k = price index of the capital good
c = costs of capital
r = discount rate
n = depreciation period

From (A.3) follows: $c = r(1+r)^{n-1} p_k / [(1+r)^n - 1]$ (A.4)

The costs of capital depend on the price of the capital good (buildings, livestock, and machinery); the discount rate; and the depreciation periods of the different components of the capital good. The prices of buildings and machinery in equation (A.4) are corrected for investment subsidies: anticipated depreciation, investment deduction and the WIR (a direct investment subsidy). The corrected price of buildings (the same hold for machinery) is equal to (Burger, 1983):

$$p_{bc} = p_b\,(1 - A - B - WIR)/(1+r)^2 \qquad \text{(A.5)}$$

$$A = \tau\,[b(1-(1+r)^{-f})/r + (1/n)(1-bf)(1-(1+r)^{-n})/r] \qquad \text{(A.6)}$$

$$B = \tau\, a\,(1-(1+r)^{-g})/r \qquad \text{(A.7)}$$

where:
p_{bc} = corrected price of buildings
p_b = price of buildings
A = advantage of the anticipated depreciation
B = advantage of the investment deduction

τ = taxation rate
b = percentage anticipated depreciation
a = percentage investment deduction
f = years of anticipated depreciation
g = years of investment deduction
WIR = percentage of the WIR

The prices of livestock, buildings and machinery were obtained from LEI/CBS, Landbouwcijfers. The discount rate used is the interest rate on mortgages, the depreciation rate is 0% for livestock, 4% for buildings and 10% for equipment. The costs of livestock is the price of livestock multiplied by the discount rate. Figures for the investment subsidies are obtained from Kluwer Fiscaal Zakboek. The capital costs for livestock, buildings and machinery are combined using a Törnqvist index, like equation (A.1).

Table A.2 Törnqvist price indices for the output, the variable input, capital, and the capital costs; base year 1980

Year	Output	Variable input	Capital	Capital costs
1970	0.65	0.62	0.64	0.033
1971	0.72	0.62	0.67	0.038
1972	0.75	0.67	0.73	0.041
1973	0.77	0.76	0.78	0.043
1974	0.79	0.79	0.74	0.049
1975	0.87	0.84	0.77	0.052
1976	0.92	0.95	0.80	0.053
1977	0.98	0.88	0.86	0.058
1978	0.98	0.85	0.92	0.059
1979	0.99	0.96	0.97	0.062
1980	1.00	1.00	1.00	0.069
1981	1.11	1.06	1.03	0.075
1982	1.15	1.08	1.07	0.072

APPENDIX B

FIXED EFFECTS MODEL AND AN UNBALANCED PANEL, USING 3 SLS

Consider the following regression model:

$$y_{jht} = \alpha_{jh} + x_{jht}'\beta_j + \xi_{jht} \qquad (B.1)$$

where j denotes equations ($j=1,2$), t years ($t=1....T$), h households ($h=1.....H$), y_{jht} is the dependent variable, x_{jht} is a k_j vector of explanatory variables, β_j is a k_j vector of parameters, α_{jh} is a fixed effect and ξ_{jht} is assumed to have mean zero. In matrix notation for a complete panel we order the $2 \cdot H \cdot T$ observations such that we first have the H observations of period 1, then the H observations of period 2 etc., for equation 1, then the same for equation 2. Then (B.1) becomes:

$$y = Z\,\alpha + X\,\beta + \xi \qquad (B.2)$$

the vectors y and ξ are of dimension $H \cdot T \cdot 2$, $Z = [\,(I_2 \otimes i_T) \otimes I_H\,]$, $i_T = (1,1,.....1)$, I_H is the identity matrix of order H x H, α is a vector of dimension $H \cdot 2$.

In an incomplete panel:

$$Z = I_2 \otimes D \quad \text{with } D = \begin{bmatrix} D_1 \\ . \\ . \\ . \\ D_T \end{bmatrix}$$

where D_t is the N_t x H matrix obtained from the H x H identity matrix where rows corresponding to households not observed in year t have been omitted. Z is of order $2 \cdot N$ x $H \cdot 2$,

$$N = \sum_t N_t$$

Wansbeek and Kapteyn (1989) show that applying OLS to data from an incomplete panel with fixed firm effects amounts to applying OLS to a model without these effects when the variables have been transformed according to the symmetric idempotent matrix P, where:

$$P = I_N - D\,(D'D)^{-1}D' \tag{B.3}$$

The P matrix transforms the observations on each farm so that they are in terms of deviations around the mean for that farm. As will be shown, this matrix can also be used to transform the data when SURE is to be used as an estimator. We assume $E[\xi\xi'] = \Sigma \otimes I_N$, where Σ is of order 2x2.

Premultiplication of equation (B.2) by $I_2 \otimes P$ gives:

$$\begin{aligned}[I_2 \otimes P]\, y &= [I_2 \otimes P]\, Z\, \alpha + [I_2 \otimes P]\, X\, \beta + [I_2 \otimes P]\, \xi \\ &= [I_2 \otimes P]\, X\, \beta + [I_2 \otimes P]\, \xi\end{aligned} \tag{B.4}$$

The covariance matrix of the transformed joint disturbance vector is given by:

$$\begin{aligned}E\,[(I_2 \otimes P)\xi\xi'(I_2 \otimes P)'] &= (I_2 \otimes P)\,(\Sigma \otimes I_N)\,(I_2 \otimes P)' \\ &= \Sigma \otimes PP' = \Sigma \otimes P\end{aligned}$$

The GLS estimator of ß of equation (B.4) has the following form:

$$\begin{aligned}\hat{\beta} &= \{\, X'\,[I_2 \otimes P]'[\,\Sigma \otimes P]^-\,[I_2 \otimes P]X\,\}^{-1} * \\ &\quad X'\,[I_2 \otimes P]'[\,\Sigma \otimes P]^-\,[I_2 \otimes P]y \\ &= \{\, X'\,[I_2 \otimes P]'[\,\Sigma^{-1} \otimes I_N]\,[I_2 \otimes P]X\}^{-1} * \\ &\quad X'\,[I_2 \otimes P]'[\,\Sigma^{-1} \otimes I_N]\,[I_2 \otimes P]y\end{aligned} \tag{B.5}$$

The second term of equation (B.5) is the GLS estimator of the β vector on the data expressed in terms of deviation from unit sample means. Therefore the β vector of equation (B.4) may be estimated by applying GLS to the data expressed in terms of deviation from unit sample means. An estimator for Σ can be calculated in the usual manner by OLS. The proof of consistency for $H \rightarrow \infty$ is straightforward. The standard errors of the estimator can be calculated in the usual manner, although one should adjust for the loss of degrees of freedom. This GLS estimator is used for the dual model. Because 3SLS is a GLS estimator the P matrix can also be used to transform the data for the primal model.

APPENDIX C

SOLVING THE DIFFERENCE EQUATION

To solve the difference equation (6.5), using the lag operator L, write it as (Sargent, 1987: 200-203; Nickell, 1986: 500-504)

$$(L^{-1} - \mu + \tau^{-1}L)\, k_{t,h} = -(\omega\tau)^{-1} z^*_{t,h} \tag{C.1}$$

where $z^*_{t,h} = \gamma_{1h} + \gamma_3 p_t + \gamma_4 k_{t,h} - c_t + s_{t,h}$

Factorizing the lag polynomial as:

$$a_1(1-a_2\lambda L^{-1})(1-\lambda L)\, k_{t,h} = -(\omega\tau)^{-1} z^*_{t,h} \tag{C.2}$$

we have, by comparing coefficients,

$$a_1 + a_1 a_2 \lambda^2 = -\mu, \; -a_1\lambda = \tau^{-1}, \; -a_1 a_2 \lambda = 1 \tag{C.3}$$

This implies that λ is a root of the quadratic:

$$\lambda^2 - \mu\lambda + \tau^{-1} = 0 \tag{C.4}$$

From the assumptions that γ_2 is negative, ω is nonnegative and the discount rate τ lies between zero and one, the stable root of (C.4), which is less than one, is given by:

$$\lambda = \tfrac{1}{2}\mu - \tfrac{1}{2}\sqrt{\mu^2 - 4\tau^{-1}} \tag{C.5}$$

Using (C.3) we can rewrite (C.2) as follows:

$$-(\tau\lambda)^{-1}(1 - \tau\lambda L^{-1})(1 - \lambda L)\, k_{t,h} = -(\omega\tau)^{-1} z^*_{t,h} \tag{C.6}$$

Or: $(1 - \lambda L)\, k_{t,h} = \lambda\omega^{-1}(1 - \tau\lambda L^{-1})^{-1} z^*_{t,h}$ (C.7)

Given that λ is less than one, this may be expanded:

$$k_{t,h} = \lambda k_{t-1,h} + \lambda\omega^{-1} \sum_{i=0}^{\infty} (\tau\lambda)^i z^*_{t+i,h} \tag{C.8}$$

APPENDIX D

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SAMENVATTING

Het bestuderen van het gedrag van de producenten in de landbouw is een belangrijk onderzoeksthema in de agrarische economie. Veel aandacht wordt daarbij geschonken aan (i) de factoren die het aanbod van produkten beïnvloeden, (ii) de factoren die van invloed zijn op de gevraagde inputs, en (iii) de invloed van de technische ontwikkeling. Veelal gebeurt dit met modellen op sectorniveau, waarbij gebruik wordt gemaakt van tijdreeksen. Nadelen van deze modellen zijn dat er nauwelijks een verband bestaat tussen empirie en de gebruikte micro-economische theorie en dat gebruik moet worden gemaakt van een beperkte dataset.

Het eerste doel van het proefschrift is om micro-economische modellen te ontwikkelen, die aan deze bezwaren tegemoet komen. Deze modellen worden gekenmerkt door een nauwe relatie tussen theorie en empirie. Dit vergroot de mogelijkheden om de gemaakte veronderstellingen te onderzoeken en verbetert de interpreteerbaarheid van de empirische resultaten. Nieuwe ontwikkelingen in de toegepaste produktietheorie (dualiteitstheorie, huishoudproduktietheorie, consistente dynamische modellen, rationele verwachtingen) en schattingstechnieken voor panel data worden gecombineerd.

Het tweede doel van het proefschrift is het verkrijgen van inzicht in de invloed van de prijs van de output, de prijzen van inputs, de hoeveelheid grond op het bedrijf en de stand van de techniek op de beslissingen van gespecialiseerde melkveehouders over de periode 1970 tot en met 1982. De beslissingen, die worden geanalyseerd, zijn beslissingen ten aanzien van de output (melk en vlees), de inzet van de variabele input (met name veevoer), de hoeveelheid arbeid op het bedrijf en de hoeveelheid kapitaalgoederen (vee, gebouwen, machines) op het bedrijf.

Uitgangspunt bij het construeren van de diverse modellen is de neoklassieke produktietheorie. Basisveronderstellingen van deze theorie zijn een optimaliserende producent, gegeven een aantal technische restricties. Voor het bouwen van een model zijn additionele veronderstellingen noodzakelijk. In elk hoofdstuk is een veronderstelling nader onderzocht:

- 'primale' of 'duale' benadering? De technische randvoorwaarden, waarbinnen het produktieproces op een agrarisch bedrijf plaatsvindt, kunnen expliciet worden weergegeven door een produktiefunctie of impliciet door een winstfunctie. Volgens de dualiteitstheorie leiden beide functies tot dezelfde weergave van de produktietechniek, in de empirie kunnen de twee benaderingen echter resulteren in verschillende representaties, met name bij het gebruik van een functievorm die niet 'self-dual' is. In hoofdstuk 2 worden de produktie- en substitutie-elasticiteiten berekend op basis van een translog produktiefunctie en een translog winstfunctie, die beide een adequate en een overeenkomstige beschrijving blijken te geven van de produktietechnologie. Omdat afleidingen bij de duale benadering eenvoudiger zijn, wordt in het vervolg van dit proefschrift uitgegaan van de duale benadering.

- 'fixed' of 'random effects'? In hoofdstuk 3 wordt, evenals in de rest van de studie, uitgegaan van een korte termijn kwadratische winstfunctie. Het belangrijkste voordeel van deze functievorm is dat expliciete vergelijkingen kunnen worden afgeleid voor de variabelen, waarin we geïnteresseerd zijn. Differentiëren van de winstfunctie naar de prijs levert een vraagfunctie naar de variabele input en een aanbodfunctie van de output op. De constante in de vraag- en aanbodvergelijking varieert over de bedrijven, hierin worden onder andere de kwaliteitsverschillen in arbeid en grond tussen de bedrijven weerspiegeld. De correcte schattingstechniek voor dit korte termijn model hangt af van de veronderstelling ten aanzien van de constante: is het een vaste parameter ('fixed effect') die geschat kan worden of is het een stochastische variabele ('random effect') en daarom onderdeel van de storingsterm? Op basis van een Hausman test worden de uitgangspunten van de 'random effects' schatter verworpen. Daarom worden in de andere hoofdstukken 'fixed effects' verondersteld.

- nuts- of winstmaximalisatie? In hoofdstuk 4 wordt het korte termijn winstmaximalisatie model uitgebreid tot nutsmaximalisatie op korte termijn. Uitgangspunt is dat het gezin het nut maximaliseert, dat het ontleent aan goederen en vrije tijd. Hierdoor wordt een relatie gelegd tussen het gezinshuishouden, dat vrije tijd en goederen consumeert, en het agrarische bedrijf, dat arbeid als input gebruikt en inkomen genereert. Het model blijkt een acceptabele beschrijving te geven van het gedrag van agrarische gezinnen. Echter de hoeveelheid arbeid die door het agrarische gezin wordt ingezet, blijkt nauwelijks gevoelig te zijn voor prijsveranderingen. Daarom is in de overige hoofdstukken uitgegaan van winstmaximalisatie.

- een dynamisch model? Om inzicht te verkrijgen in de invloed van veranderingen in de prijzen, de hoeveelheid grond en de stand van de techniek op de beslissingen van agrariërs op middellange en lange termijn wordt in hoofdstuk 5 een dynamisch model ontwikkeld. Uitgangspunt van dit model is dat het agrarische gezin de contante waarde

van de toekomstige inkomsten maximaliseert. Op basis hiervan wordt, evenals in de andere hoofdstukken, de korte termijn winst gemaximaliseerd, gegeven de kapitaalgoederenvoorraad. Het aanpassen van deze quasi-vaste input gaat met aanpassingskosten gepaard. De geschatte aanpassingparameter, die de aanpassing van de feitelijke aan de optimale kapitaalgoederenvoorraad weergeeft, is zesentwintig procent. De aanname van een volledige aanpassing van alle inputs aan de optimale hoeveelheid wordt daarom niet gehanteerd in dit proefschrift.
- statische of rationele verwachtingen? In hoofdstuk 6 worden twee modellen ontwikkeld. In het ene model wordt uitgegaan van statische verwachtingen ten aanzien van het toekomstig verloop van prijzen en de vaste inputs arbeid en grond. Dit model blijkt goed aan te sluiten bij de data. In het andere model, gebaseerd op rationele verwachtingen, wordt verondersteld dat het agrarisch gezin alle informatie die op een bepaald moment aanwezig is, gebruikt om de variabele input en de quasi-vaste input optimaal in te zetten. De resultaten van dit model zijn niet consistent met de theoretische uitgangspunten. Dit kan worden veroorzaakt door een verkeerde specificatie van het model, niet optimaal gedrag door het agrarisch gezin, of niet-rationele verwachtingen ten aanzien van het toekomstig verloop van de prijzen en de hoeveelheden inputs.

Op basis van de ontwikkelde modellen zijn elasticiteiten ten aanzien van prijzen en (quasi-) vaste inputs berekend. Er bestaan verschillen tussen de resultaten van de verschillende hoofdstukken. Dit kan worden veroorzaakt door
- verschillende modellen: in de hoofdstukken 2 en 3 wordt uitgegaan van korte termijn winstmaximalisatie, in hoofdstuk 4 van nutsmaximalisatie, en in de hoofdstukken 5 en 6 wordt uitgegaan van maximalisatie van de contante waarde van de toekomstige inkomsten. In hoofdstuk 5 is tijd continu verondersteld en worden vele cross-restricties op de parameters geïntroduceerd. In hoofdstuk 6 is tijd discreet verondersteld en zijn er geen cross-restricties op de parameters.
- verschillende schattingstechnieken: in de hoofdstukken 2, 3 en 4 wordt een 'fixed effects' schatter gehanteerd, in de hoofdstukken 5 en 6 wordt een eerste verschillen schatter gehanteerd. In hoofdstuk 6 wordt een uitgebreide set van instrumentele variabelen gebruikt.
- verschillen in de data: het aantal observaties in de hoofdstukken 5 en 6 is kleiner dan in de hoofdstukken 2, 3 en 4 omdat in de hoofdstukken 5 en 6 eerste verschillen van de variabelen zijn gehanteerd. In hoofd-

stuk 6 zijn alleen bedrijven, die minstens vijf achtereenvolgende jaren in de steekproef voorkomen, gebruikt.

De verschillen in de resultaten zijn niet groot. Een aantal conclusies ten aanzien van het effect van veranderingen in de prijzen, de hoeveelheid grond op het bedrijf en de stand van de techniek op de beslissingen van de melkveehouders zijn dan ook te trekken.

De prijselasticiteiten van het aanbod van de output en de vraag naar de variabele input zijn zeer gering op korte termijn. De korte termijn elasticiteiten van kapitaalgoederen en met name de hoeveelheid grond zijn niet gering. De invloed van de hoeveelheid grond op het aanbod weerspiegelt de schaarste van grond in het produktieproces. Dit in tegenstelling tot kapitaalgoederen, waarbij het effect op het aanbod grotendeels wordt veroorzaakt door de positieve invloed van de omvang van de kapitaalgoederenvoorraad op de vraag naar de variabele input. Variabele inputs en kapitaalgoederen zijn complementair. Technische ontwikkeling heeft een gering effect op de ligging van de produktiefunctie, maar wel een groot indirect effect op het aanbod door een toename van het gebruik van de variabele inputs.

Op middellange en lange termijn vindt een aanpassing plaats van de hoeveelheid kapitaal bij met name veranderingen van de prijs van de output, de kapitaalkosten (die mede afhangen van investeringssubsidies) en de technische ontwikkeling. De investeringen in kapitaalgoederen zijn zelfs zeer gevoelig voor veranderingen van deze factoren. Prijsbeleid is daarom een bruikbaar instrument om investeringsgedrag te beïnvloeden.

Echter de prijselasticiteiten van het aanbod van de output en de vraag naar de variabele input blijven ook op middellange en lange termijn gering. Dit wordt veroorzaakt door: (i) een beperkte omvang van de elasticiteiten van het aanbod van de output en de vraag naar de variabele input ten aanzien van kapitaal, (ii) de investeringen zijn weliswaar op korte termijn prijsgevoelig echter de vraag naar kapitaalgoederen is niet erg prijsgevoelig, ook niet op lange termijn.

Als gevolg hiervan zullen niet al te grote prijsveranderingen van de output en de variabele input, in het kader van het EG prijsbeleid of in het kader van milieubeleid, nauwelijks effect hebben op de vraag naar de variabele input en het aanbod van de output, zelfs op lange termijn. Veranderingen in de vraag naar de variabele input en het aanbod van de output worden grotendeels bepaald door de technische ontwikkeling en veranderingen in de hoeveelheid grond op het bedrijf.